Oceanographic Information for the Eastern Canadian Offshore

Adequacy for Exploratory Drilling

A Report to

The Royal Commission on the Ocean Ranger Marine Disaster

By

Seaconsult Limited

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SUMMARY

Exploratory drilling units operating off Canada's East Coast must take certain oceanographic conditions into account, both for design and selection of the appropriate vessel or jackup rig, and for safe operations at sea. The most important of these are extreme currents and extremes of temperature. This report contains a review of oceanographic information for the offshore area extending from the Southern Scotian Shelf to Baffin Bay. Relevant oceanographic parameters are first defined and measurement techniques widely used now to quantify them are outlined. Analysis methods and predictive models are then discussed, followed by a description of available data and their distribution. Finally conclusions on the present state-of-knowledge and adequacy of data for drilling needs are presented.

In describing ocean currents and water masses, basic physical parameters (current speed and direction at a point, temperature, salinity, and density) are, and have always been used in modern oceanography. These paremeters are entirely appropriate because they are fundamental to a dynamical understanding of currents, and they can be measured with acceptable accuracy. Measurement techniques were found to be generally adequate. It was noted that Aanderaa current meters, which do not have vector averaging capability, are still the mainstay of current measuring programs; improvements in data quality would accompany their replacement with vector averaging instruments.

We also found no evidence to suggest that analytical techniques are inadequate for data being collected in Canadian waters. Problems that do exist have more to do with what data were collected, and where, than with analysis methods used on them.

Predictive models for extreme currents, other than the tidal components, rely on long-term time series measurements. It has been shown, for example, that to achieve a 10% error in the variance of mean currents about 30 years of data are required. These data are not available in the offshore area, with the result that estimates of current extremes produced by factors other than tide, and, perhaps, wind, have very low confidence.

Methods for hindcasting wind-driven currents, using either empirical or deterministic models are available, but to date have not been applied for the region. Over the Northern Grand Banks, the Scotian Shelf around Sable Island and Lancaster Sound there are sufficient data to attempt this form of modelling with an opportunity to verify the results.

In many locations there are now good data records for tidal currents analysis and prediction, and reliable estimates of extreme tidal currents can be made. The major difficulty lies in extending current data from one site, where measurements have been made, to another without data. Numerical tidal modelling could assist in this, but to date there are no model data north of the Gulf of Maine and there is a severe lack of open ocean tidal data with which to operate these models elsewhere.

Measured current data were found to have originated from three main sources: government scientific research, industry baseline studies of a regional nature, and industry deployments in conjunction with well drilling. Considered together in terms of their spatial and temporal distributions, it appears that no master plan for making measurements has evolved that is oceanographically sensible. Data available

now form a haphazard set of short-term records largely clustered around areas of active drilling or discovery. Systematic long-term measurements at locations strategic for delineating major currents or providing input data to predictive models have not been made. Consequently available data are largely inadequate for deriving current extremes with the confidence one normally associates with wind and wave criteria. In certain areas, Hibernia, Venture and Lancaster Sound, there are data with which to make estimates, albeit with low statistical confidence. Removed from these sites, however, it is extremely difficult to specify design currents having an accuracy equivalent to wind and wave criteria.

Canadian practice for archiving data has been fragmented such that water property, water level, wind, wave, and current meter data are all stored in separate databases often at different locations, and following different formatting systems. As a result it is a difficult and frustrating process to assemble the concurrent records needed for a proper dynamical evaluation of ocean currents. This archiving procedure mitigates against use of those few data that are available for estimating current extremes other than by the most basic statistical methods. Moreover, designers are increasingly turning their attention toward joint occurrences of extremes in wind, waves and currents. The organization of historical data makes this type of analysis difficult also.

Thus, from an oceanographic perspective we have found many shortcomings in where data have been collected and how they are stored for later use, and these have a direct impact in how well design currents can be evaluated. We also note, however, the existing data, scientific interpretation of

them and industry studies have not revealed conditions that are beyond the drilling technology in use today, nor that appear to be limiting for design over most of the East Coast. A decade of offshore experience has also failed to turn up serious problems that could be attributed to ocean currents or extremes of temperature. The effects of waves and ice are much more serious.

As a result it cannot be concluded that present oceanographic knowledge is inadequate for offshore drilling needs as they impact on safety. With the exception of Hudson Strait and Flemish Pass necessary criteria on currents, water levels, and water properties can be estimated and adequately allowed for in design. In these two areas, however, and in deeper water along the continental shelf break, more data will likely be needed to plan safe drilling programs.

In view of our findings on oceanographic practices and anticipating an expanding offshore drilling industry, it would seem logical to reorient data collection along more rational lines than are presently followed. Essential aspects would include:

1) establishing predictive techniques and data requirements for current extremes;

2) organizing long-term strategic monitoring stations for all necessary parameters;

3) standardizing instrumental and analytical techniques; and

4) putting all data into one archive suitable for a dynamical analysis of winds and currents, in combination with wind waves.

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1. INTRODUCTION

Oceanographically, the Canadian east coast offshore region presents a highly varied environment to the hydrocarbon exploration and development companies. Most regions experience visually dramatic seasonal changes -- frequent severe storms and possibly the presence of pack ice in the winter, but relatively calm, temperature conditions in the summer.

The sites of greatest geological interest range from the extreme southern limit of Canadian waters to Baffin Bay including some large, confined water bodies such as the Gulf of St. Lawrence and Hudson Bay. Exploratory drilling sites have been selected on wide flat plateaux like the Grand Banks; in bathymetrically complex regions such as the Scotian Shelf which is composed of banks, basins and submarine canyons; in the saddles of the Labrador Shelf; on sand bars a few tens of meters below the surface; on the edge of the continental shelf in more than 1000 m of water; in the paths of major oceanic currents; in regions with extreme tidal current fluxes like the mouth of Hudson Strait. Even the two sites of significant hydrocarbon discoveries present strong contrasts. Venture is a shallow 20 m deep site, partially sheltered by Sable Island, that is not threatened by sea ice. Hibernia, on the other hand, is a moderately deep 80 m site on the northeast corner of the Grand Banks which is somewhat influenced by the Labrador Current and is exposed to influxes of both pack ice and icebergs.

To cope effectively with this wide range of environmental conditions, exploratory drilling companies have utilized a variety of drilling units -- dynamically positioned drilling vessels (ship-shapes) for the short seasons in ice-infested waters like Davis Strait and the

Labrador Shelf; semi-submersibles for year-round drilling on the Grand Banks and at deep Scotian Shelf sites; jack-up rigs for shallow sites like Venture that are not threatened by ice. Undoubtedly similar contrasts will be present in the evolving production facility designs.

The environmental criteria for exploratory rig selection depend somewhat on the type of unit chosen. For example, water level is a crucial paremeter for jack-ups, but is relatively unimportant for floating units at deep water locations. For rig design, which in the Canadian context is almost exclusively limited to hydrocarbon production facilities, the data requirements for design criteria are more demanding than simply for rig selection. The production unit may have a longer expected life and no opportunity for shore-based inspections and repairs. It is exposed to the same environmental stresses throughout its life-time which is normally a more severe design condition.

In terms of data requirements, design needs longer environmental monitoring to predict extreme events with confidence. Rig selection for exploratory drilling is frequently based on a few weeks or months of data, sometimes from a different but similar region of the world. For design criteria in harsh environmental conditions that may have been poorly monitored historically or may be highly variable spatially or temporally, there is no substitute for the longest possible local time-series of relevant environmental parameters.

There are further data requirements in order to conduct drilling operations effectively. Some operations are sensitive to even moderate environmental forcing -- diving, for example, and installation of the blowout prevention unit. Predictive sea ice drift and iceberg management are other aspects of offshore drilling that require real-time, as opposed to historical, data input.

The purpose of this report is to look at the adequacy of oceanographic data for offshore "design" and operations from a number of perspectives. The first objective was to identify the oceanographic parameters of consequence and to describe which aspects of offshore hydrocarbon exploration are sensitive to them. This material is discussed in Chapter 2, organized by the parameters of concern.

Having identified the types of data that are required, Chapter 3 describes the instrumental techniques that are now routinely used to collect that data. Where appropriate, obvious limitations in present data collection techniques are discussed and promising new instruments that are still in experimental stages of development are mentioned. Chapter 3 is also organized by oceanographic parameters.

With some understanding of data collection, Chapter 4 proceeds with descriptions and examples of data analysis techniques that are customarily used to extract meaningful information from time-series measurements. The emphasis here is on explaining the methods of obtaining the specific data components that are used in the offshore design process.

Chapter 5 addresses environmental predictive methods from two points of view: data analysis for the derivation of long-return period extremes of current velocity and water levels, and modelling of the two or three-dimensional current structure as an aid in operations like iceberg management. The subject of currents modelling is of necessity somewhat philosophical since the most promising approaches are largely untested.

The historical archives of oceanographic data are outlined briefly in Chapter 6. Details of the data collection, archiving and dissemination responsibilities are included for industrial, university and government agencies.

Chapter 7 recapitulates and expands upon deficiencies noted in each of the preceeding topics: measurement, analytical, and predictive techniques, data acquisition and archiving procedures. Certain aspects of the present regulatory requirements for oceanographic monitoring are discussed with respect to the problem of planning data collection programs to provide historical databases for design purposes.

2. OCEANOGRAPHIC PARAMETERS

Within the context of this report, three oceanographic parameters are discussed: currents (near-surface and deep), water levels, and fundamental sea water properties (temperature, conductivity, salinity, density and dissolved oxygen). Of these, currents are the most important to the design and execution of offshore exploratory drilling programs. In addition to considering near-surface, wind-dominated currents and those below the mixed layer, internal waves are also discussed in the context of the currents they generate. The purpose of this section is to define these parameters so that it is clear how they arise in oceanography, and so that instrumental and analytical techniques to measure them can be appreciated.

2.1 Near-Surface Currents

Near-surface currents are those associated with the mixed layer of the ocean. The depth of this layer depends crucially upon the wind, and upon solar insolation and freshwater run off; hence in most offshore locations it varies strongly with the seasons. On the Grand Banks, for example, the mixed layer is about 25 m deep in August, but increases to about 100 m during the stormy January and February months. In contrast, on Sable Island Bank in water depths less than about 50 m, the ocean is vertically well mixed to the sea bed throughout the year.

Present governmental regulations require that at each offshore exploratory drilling site currents are measured at 20 m depth, and these data are taken to be representative of the mixed layer. Near-surface currents

are logged for post-season analysis and archiving on magnetic tape by a moored current meter remote from, but in the vicinity of, the exploratory well site. Because they are recorded rather than transmitted, these data have no operational significance. Typical near-surface currents are 60 to 80 cm/s in the winter near Hibernia, on the order of 100 cm/s near Sable Island, and 50 to 75 cm/s along the northern Labrador Coast.

There is a further regulatory requirement for real-time near-surface measurements that are displayed and recorded on the drilling unit as an operational aid. These data are subject to local disturbances (e.g. thrusters and drilling vessel motion) and are not usually quality controlled or archived. This instrument is normally suspended on a winch wire to be raised or lowered as required. The greatest use of this data is in support of diving operations or iceberg towing.

In contrast to these Eulerian (point) measurements of the current, Lagrangian (drifting) measurements may also be made. Drogued satellite-tracked buoys may be used to estimate a depth-averaged current to aid in iceberg drift prediction and buoys or surface floating cards can be used to simulate the spread of oil on the sea surface. Because of the expense of data collection using drifters, and some difficulties of interpretation, measurements using current meters operated from ships are more widely used.

Near-surface currents are required for several aspects of the design of an exploratory drilling program. In the design or selection of a floating drilling unit,

currents are a component of the fluid loading calculations, particularly for considerations of stationkeeping such as thruster capacity or anchor loads. In places like Hudson Strait where near-surface currents can reach 250 cm/s (5 knots), currents are as important a factor in the overall assessment of drilling feasibility as are waves and ice conditions.

At shallow sites where the water column is vertically mixed (e.g. Sable Island Bank), extreme wind-driven currents in conjunction with strong tidal flows over shallow bars produce appreciable scour around the footings of jack-up platforms. Scour considerations determine in part how far footings are jetted into the sea bed to ensure platform stability.

Operationally, near-surface currents are important input data for ice management, oil spill contingency planning and countermeasures, search and rescue, diving, and the safe transfer of men and equipment from supply vessels (especially in conjunction with severe winds and waves). However, the same estimate of the current will not suffice for each of these needs. For ice management, a depth averaged current is usually required; for oil spill tracking the current within the top 10 cm is needed; for search and rescue the average current in the top 1 to 2 m is best. In fluid loading calculations, the average current over the draft of the vessel (or iceberg) is used, or at an added level of refinement, a continuous current profile may be required. In most situations, it is impractical to use conventional moored current meters at depths less than 10 to 20 m. At shallower depths they are too susceptible to damage by ice or supply vessels and they may even surface in the troughs of large waves.

Historical current data archives are a source of information for drilling unit design or selection. To be useful however, these data must have been recorded over a sufficient duration in comparable locations. In remote areas, these data generally have to be collected in advance of exploratory drilling (as was done in Davis Strait in the mid-1970's).

For the operational requirements historical data are wholly inadequate. For ice management, search and rescue, and oil spill countermeasures a point measurement, even reported in real-time, is of little use unless the currents exhibit strong spatial coherence. What is required is the two-dimensional description of the field of flow a few kilometers upstream of the drilling site for ice management and many kilometers downstream for oil spills. However, the collection of such data by arrays of current meters is not economically feasible, but CODAR developments (see e.g. LeBlond, 1984) may provide the necessary technological break-through.

2.2 Subsurface Currents

In this report, subsurface currents refer to the flow in the region below the mixed layer and above the bottom boundary layer, that is, about 5 m above the sea bed. These currents are composed of tidal, density-driven (geostrophic) and wind-driven circulation. The last component may be observed at the local inertial frequency (which is a function of latitude) and also at "super-inertial" frequencies.

At each exploratory drilling site, COGLA requires measurement of currents at mid-depth and at about 20 m above the sea bed. These data are recorded on magnetic tape for post-season analysis and archiving and, as a result, they have no operational significance while the rig is drilling on site.

Typically subsurface current magnitudes are smaller than the near-surface values. Large observed mid-depth currents are in the range 40 to 50 cm/s on the Grand Banks and 40 to 60 cm/s in 150 m of water off Labrador. Near-bottom currents are generally less, except in shallow waters like the Scotian Shelf where they may exceed 40 to 50 cm/s.

Bathymetry and coastal topography are important modifiers of subsurface currents. The ridges and saddles of the Labrador Shelf are examples of bathymetric features which exert strong controls on the flow of the major coastal current there. The very large currents observed in Hudson Strait are partially due to restricting topography and a relatively shallow sill at the mouth of the strait which together create a constriction to the tidal discharge.

From the design point of view, subsurface currents are a critical factor in the fluid loading calculations on marine risers. They determine both the design strength of the riser and requirements for additional buoyancy. Operationally they are important during the initial well spudding, when landing the blowout preventor unit, and during diving operations. In addition they may be input data to iceberg management schemes.

Ocean currents are often characterized by changes in direction over depth. Referred to as shearing currents,

they are potentially problematic for diving, the operation of remotely controlled submersibles, and certain drilling activities. They may be caused by features in the continental shelf bathymetry, density-driven flows,and internal tides generated at the shelf break. In waters deeper than about 50 to 75 m, a 3-point parameterization of currents as described above is, in general, not adequate to resolve variations in currents over depth characterized by strong vertical shear.

2.3 Water Levels and Depths

In hydrographic charting, bathymetric features are specified relative to a chart datum which is defined by properties of the local tide. Variations of the sea surface about datum are the result of tides, storm surge, long-term atmospheric fluctuations, tsunamis and, of course, wind-waves. The establishment of chart datum and the variations of total water depth are an element to be considered in floating drilling operations, but are only critical in the sizing of jack-up rigs to ensure sufficient air gap below the drilling platform. Even in this latter case, however, the uncertainty in water depth is usually much less than in the other factors controlling air gap (storm surges and design waves). The Canadian Hydrographic Service is responsible for charting in Canadian waters. In conjunction with local detailed surveys by offshore oil company operators, adequate specification of depth below chart datum should always be achieved.

Specification of the expected tidal range is based on prediction from measured tidal data usually from shoreline stations which are not necessarily representative of offshore conditions. Coastal topography may amplify

the tidal range as it does in Frobisher Bay and Ungava Bay. Since the tidal range decreases with increasing distance from shore, the lack of precise tidal calculations for offshore locations is less important.

Storm surge accounts for water level changes along coastlines and at sites like Sable Island that are large enough to be of concern. It also needs to be carefully considered in semi-enclosed basins like the Gulf of St. Lawrence where storm surge may double the water level change due to tide alone (Briand, 1980).

Tsunamis are long ocean waves produced by earthquakes. They are rare events in Eastern Canadian waters and almost no data exist on wave amplitudes. The tsunami following the 1929 Grand Banks earthquake caused considerable destruction along the Burin Peninsula in Newfoundland, but was undetected at Sable Island and only weakly present at Halifax. Tsunamis may be strongly amplified by coastal features, and slightly amplified as they propogate from the deep ocean onto continental shelves where drilling activity is presently centred. Wave amplitudes on the shelves are expected to be of the order of one metre, increasing to several metres in narrow coastal inlets.

2.4 Sea Water Properties

The fundamental properties of sea water, as measured, are temperature, conductivity and dissolved oxygen. From the first two values, salinity may be calculated; from temperature, salinity and pressure sea water density and sound speed in water are determined.

Few design criteria or operational considerations rely on precise knowledge of any of these properties. Expected temperature ranges are a consideration in the design and selection of drilling fluids and in the selection of steels for rig fabrication. Sea surface temperature is also an important parameter in meteorological modelling for weather prediction.

Temperature, salinity and dissolved oxygen are factors in estimating biofouling potential and the corrosion of metals. Sound speed is essential in the calculations for the accurate reduction of bathymetric soundings.

Water density enters buoyancy calculations, in marine riser design for example. Density, as a function of depth, is important input data to a variey of models -- it is fundamental in geostrophic current calculations; it may be a controlling parameter in oil-gas blowout plume behaviour at deep, cold water locations, and it controls the vertical exchange of momentum in wind-driven current models.

Conductivity and temperature data are routinely collected by the three moored current meters at each exploratory drilling site. As an historical database, these measurements are useful for design requirements, but they are too imprecise (only 3 points over the water column) to be useful for most modelling applications. The temperature data are of no use for weather prediction as they are not reported in real-time.

2.5 Internal Waves

Internal waves propagate on the interface between the mixed layer and the deep ocean. Their presence has been reported in many parts of the world including Davis Strait

(Hodgins and Westergard, 1981), but severe activity is a localized phenomenon. In Davis Strait, for example, large amplitude internal waves are apparently generated through tidal interaction with local bathymetry and usually appear in groups of 2 to 5 waves every 12.5 hours. Currents associated with their passage may peak at 2 to 2.5 knots with a roughly 10 minute wave period. The result is a rapid and large change in water density and velocity as the wave passes. The most severe events in western Davis Strait can push a dynamically positioned drilling unit off site. If they are anticipated and the ship can avoid taking the force broad-side, their effect can be minimized. Although there is no verified theory to explain or predict their presence, their predictability in practical terms is readily linked to the tide and a little experience can reveal the wave's prevalent direction of travel.

3. STATE OF THE ART MEASUREMENT TECHNIQUES

Advances in electronics in recent years have enabled the measurement of a number of oceanographic parameters to a level of accuracy considered in the realm of science fiction only a decade ago. Equal improvements in equipment reliability have developed more slowly. To be useful to design engineers, offshore operators, and scientists, oceanographic data must be not only accurate but also interpretable. The nature of the sea does not make either of these objectives easily attainable.

A major factor that often reduces the usefulness of field data is the almost inevitable loss of some of it through mechanical or electronic malfunctions or due to human error. Data recovery rates considered acceptable for engineering purposes, and attainable under operational conditions, are 70 to 80 percent (Woodward et al., 1978). The largest portion of the last 20 to 30 percent is atttibutable to loss of instruments (especially in ice-infested waters like Labrador), water leakage and instrument damage on deployment. In these cases, the failure occurs suddenly and irreversibly. Unfortunately, intermittent data loss also happens and the confidence with which the time-series of measurements can be reconstructed may be very low. This circumstance can be a serious limitation to the use of historical data which may not have been carefully processed and documented.

Another uncertainty in historical data can arise from unknowns in instrument calibration procedures. The importance of frequent, reliable calibration of all oceanographic instruments cannot be overstated as it is the only way to assure their performance to specification. This calibration takes two forms:

(1) checking the correct operation of the electronics in a thorough way; and

(2) verification of correct measurement against a standard. The quality of the standard is variable to some unknown extent unless it is based on international standards. For current meters calibration includes a zero check on velocity, a series of velocity calibrations in a tow tank, and the development of calibration curves for pressure, temperature, conductivity and direction.

A curious, somewhat contradictory problem accompanies some modern instruments, particularly those that sample and report in real-time -- too much data. Very large data volumes are not frequently useful and may preclude complete analysis or archiving. Intelligent use of microprocessors within the instrumentation to calculate average measures is now practical and becoming more common.

In the following sections, the emphasis is placed on describing those instruments and field techniques that are currently used, including identification of their limitations. Brief descriptions of new devices that are coming available for offshore applications are also presented.

3.1 Currents

Traditionally there were two ways to measure currents: drift with them and see where they led -- the Lagrangian method; or put a device in a single location and measure the speed, direction and perhaps other parameters as the water mass flows by the -- the Eulerian method. Both of

these methods are routinely used: the Eulerian one is more applicable to engineering design needs and certain operational considerations; the Lagrangian method is most frequently used to trace the movement of surface water with applications to oil spill tracking and sea ice movement. Development efforts are presently being directed at devices like the doppler profiling current meter, and CODAR to provide current maps by remote sampling techniques.

3.1.1 Eulerian Current Measurement

Eulerian current meters are usually moored in the water column in a system of buoys and anchors as shown schematically in Figure 3.1. They may also be suspended from a fixed or moored structure, in which case they are normally on a winch line to allow flexibility in choosing the depth of measurement. The moored systems are used to collect historical data, that is, data recorded within the instrument on magnetic tape for post-deployment analysis and archiving. The winch operated meters report in real-time to provide information for operational decisions, and as a result the data are not necessarily as suitable for analysis and storage as are the data from moored systems.

There are three basic methods of measuring ocean currents flowing past a point:

- mechanically by counting revolutions of a rotor, screw, fan or cup device,

- acoustically by measurement of the Doppler shift in reflected acoustic signals transmitted and received by the instrument; or

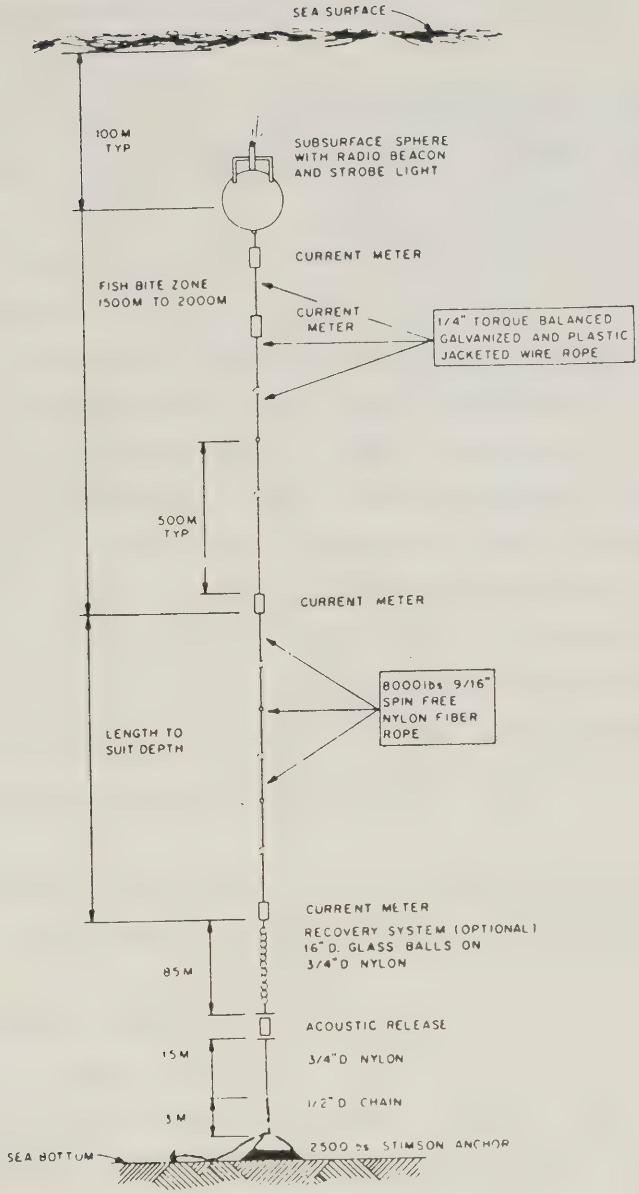


Figure 3.1 Typical ocean mooring used to deploy current meters or other instrument packages.

- electromagnetically by measurement of induced voltages produced as seawater passes through an electromagnetic field generated by the meter.

A summary of technical specifications of eight current meters that are readily available in North America is presented in Table 3.1. Literally dozens of additional types of instruments are available from virtually every industrialized country. The InterOcean S4 instrument is a new device and while it appears to be ideal for historical measurement and cost effective, it is unproven. The Simrad UCM is also unproven in Canada. Others not mentioned, such as the Weller Current Meter built by Deep Ocean Work Systems, have not gained popularity. The standard state-of-the-art instrumentation used offshore North America is covered in the remaining six devices. Most of these meters can also sample and record pressure, water temperature and conductivity; the exceptions are noted in Table 3.1.

For moored applications, as opposed to profiling uses, there are four available and proven instruments:

- the Aanderaa RCM4
- the Neil Brown ACM2
- the Marsh-McBirney 585, and
- the Endeco 174

These four meters are all reliable given proper maintenance, handling and installation, and they use magnetic tape data recording which allows fairly simple recovery of the data.

There are two common circumstances which cause problems in moored systems. The first of these is high frequency motion in the mooring line caused by internal waves and

Table 3.1 Current Meter Specifications

			VELOCITY (cm/sec)					DIRECTION			TILT°		TEMPERATURE (°C)				CONDUCTIVITY(mmho)					PRESSURE(dbars)				
	MOORED	PROFILING	TYPE	MINIMUM	MAXIMUM	ACCURACY	RESOLUTION	COMPASS TYPE	RESOLUTION	ACCURACY	MEASURED	ALLOWABLE	MINIMUM	MAXIMUM	RESOLUTION	ACCURACY	TYPE	MAXIMUM	MINIMUM	RESOLUTION	ACCURACY	MINIMUM	MAXIMUM	RESOLUTION	ACCURACY	* RECORD [illegible]
Ametek Straza		X	AC	0	375	0.5	0.25	M	GYROCOMPASS INPUT		NOT APPLICABLE						NOT APPLICABLE					NOT APPLICABLE				
Aanderaa RCM4	X		M	2.5	250	1cm/s or 2%	-	M	0.35	7.5°	NO	39°	-2.46	36.04	0.1%	0.05	I	77	0	0.01%	0.025	0	2000	0.1%	1%	10
Neil Brown ACM2	X		AC	0	250	1cm/s or 5%	-	F	-	2°	NO	30°	-2.4	35.9	0.15	0.5	I	70	10	0.02	0.05	0	1000	0.1%	0.5%	525
Neil Brown DRCM		X	AC	0	250	±5% or± 1cm/s	0.05	F	-	2°	YES	±30°	-3.0	32.7	-	0.05	I	70	10	0.02	0.05	0	1000	0.1%	0.5%	-
Marsh-McBirney 585	X		EM	0	300	±2% or ±0.07	0.005	M	1.4°	2°	NO	±45°	NOT AVAILABLE				NOT AVAILABLE					0	2000	0.7	0.1%	15
Endeco 174	X		M	2.6	360	±3%	2.5	M	1.0	2%	NO	*	-5.0	45.0	0.1	0.2	I	55	5	0.1	0.05	NOT AVAILABLE				28
Inter Ocean S4	X		EM	0	350	2% or± 1cm/s	0.2	F	0.5	2°	NO	±25°	-2.5	36.0	0.05	±0.1	I	70	1	0.1	±0.2	0	1000	1	5	40
Simrad UCM	X	X	AC	0	250	-	0.02	M	0.35	7.5°	NO		-2.0	38.0	0.01	-	I	77	0	0.1%	0.025	-	-	-	-	30

TABLE 1. TYPE:
M = Mechanical
AC = Acoustic
EM = Electromagnetic

F = Fluxgate
M = Magnetic

*Free Floating

I = Inductive
C = Conductive

small scale fluctuations in the currents. This motion is compensated for by very rapid sampling and vector-averaging of the measured components. The second problem arises from the orbital velocities induced by surface waves. These are current constituents that reverse direction every few seconds, flowing in the direction of wave propagation under the crests and flowing against it under the troughs.

Of the four current meters in widespread use, the most frequently deployed one, the Aanderaa RCM4, uses a mechanical Savonius rotor that in effect, records an average scalar speed and determines direction from an instantaneous compass reading. It cannot, therefore, compensate for wave-induced orbital currents and as a result its current speed signal may be seriously contaminated by "rotor pumping" if it is deployed too near the surface. In severe sea states, depths of 100 m may be "too near" although these instruments are regularly moored at 40 m below the surface on the Grand Banks in accordance with Federal regulatory guidelines.

In poorly designed moorings or in flows that exceed the design current magnitudes, fluid drag may cause the mooring line angle to exceed the allowable instrument tilt (see e.g. Hodgins, 1983, for a discussion of mooring behaviour in very large currents). As shown in Table 3.1 this tilt limit varies between 25° and 45°, depending on the type of current meter. Since the mooring line under fluid loading is parabolic in shape, near-bottom meters are most susceptible to extreme tilting. Strategic placement of buoyancy can be used to minimize tilt and increase the validity of data.

Measurement of the current at the ocean's surface is not a straightforward task. Since the surface is not in

general a smooth level plane, the use of instruments at a fixed depth is impossible. They are normally positioned at least 15 to 20 m below the still water level to obtain estimates of the currents that are representative of the upper, wind-driven layer. Such data, together with an assumed shape for the velocity profile over the depth of the upper oceanic layer provide input to design calculations of fluid loading on fixed or moored structures and on marine risers. If collected in real-time, near-surface current data may be used in predictive iceberg drift models.

Within the last 3 or 4 years it has become accepted practice to deploy only vector-averaging current meters in the wind-driven layer to overcome rotor pumping and mooring motion contamination of the current measurements. Two instruments account for most of the near-surface data being collected in the Canadian offshore -- the Neil Brown ACM2, an acoustic device and the Marsh McBirney 585, an electromagnetic current meter. Unlike the Marsh McBirney meter, the Neil Brown can be acquired with temperature and conductivity sensors. The ACM2 data is more complicated to process, however, since (being an acoustic device) it requires an estimate of sound speed in water at the time of sampling to calculate the current component magnitudes.

Profiling measurements, that is to say measurements taken throughout the water column including the near surface zone, are usually made by lowering an instrument on an electromechanical cable from the drill vessel. In practice these are real-time measurements, concentrated on either the near-surface or the near-bottom currents. Although electronic reliability is good, the mechancial aspects of signal transmission such as connectors, cabling and slip rings often cause problems.

There is little standardization in the use of profiling instruments or in the logging of the data. Its application is almost entirely in aid of operations like diving and BOP handling, and hence it receives little attention until it is needed.

New remote profiling instruments like the Ametek Straza show promise since they are fixed in place and rely on the transmission and reception of acoustic signals to measure the currents at different depths. These instruments can be mounted on the sea bed to measure upwards or on the bottom of a drilling vessel to sample downwards. This latter mode is the only one attempted in the Canadian offshore to date. Aside from the high cost (around $100,000), the major limitation of these doppler profiling devices is that they cannot sample near or "behind" the transducer. For hull-mounted, downward-looking instruments, this means that current measurements cannot be made in the upper 10 to 25 m of the water column. The big advantage of these devices is a complete current profile (about 5 m vertical resolution) obtained rapidly (≃60s) without the complication of electromechanical cables and the danger of fouling the instrument in drilling gear.

3.1.2 Lagrangian Current Measurements

The measurement of surface or near-surface currents by Lagrangian methods is a fairly common technique undertaken for large-scale circulation definition or for specific tracking applications. Large-scale circulation projects to define the movement of water masses is accomplished by the release and tracking of large drogued

or undrogued drifters that are designed to follow the water with minimal wind effect. They can be tracked by radar, aircraft, surface vessels or satellite. The per unit expense (up to $15,000.00) and the cost of acquiring and processing the position information usually prevents their release in large numbers.

The most commonly used Lagrangian drifter of this type is built in Dartmouth, Nova Scotia by Hermes Electronics. When tracked by satellite it returns typically 4 to 6 position fixes per day together with temperature and barometric pressure. The majority of these drifter deployments is for the Atmospheric Environment Service rather than in aid of offshore hydrocarbon exploration.

Smaller Lagrangian drifters are used as oil slick following devices to enable the tracking of individual water or oily water masses. These drifters, which are kept on board all rigs operating offshore Canada, are relatively effective as oil slick followers depending on sea state and wind conditions. A radio signal allows their tracking by directional radio location techniques. Drifters of this type are manufactured in Canada by Novatech and Orion.

A technique rarely used in open ocean is the release of dye and subsequent tracking by fluorometry or photography. Interest in the small-scale processes occurring in the open ocean has not traditionally been very high, and although dyes allow investigation of vertical mixing and dispersion, their use is not common at sea.

Each of these methods, while useful in the noted applications, involves a high level of field support and

interpretation. As a result, Eulerian measurements which are less expensive to obtain and are directly useful in offshore structural design are much more routinely collected than Lagrangian data.

The potential for a very significant improvement over traditional Lagrangian drifters as measurers of spatial variability in currents is presented by CODAR devices. This technique, which is as yet in developmental stages, uses the backscatter of radio signals from small surface waves to calculate currents at the ocean's surface. CODAR systems consist of a transmitter and two receiver antenae that are several kilometers apart. It is possible to map surface currents over large regions, on the order of 500 to 1000 km^2. It is potentially a very valuable operational tool for estimating iceberg paths; for predicting sea ice drift, oil spill trajectories and drilling waste dispession; and for aiding in the location of vessels adrift. At its present stage of development, however, a CODAR unit must be fixed on a very stable platform. This limitation and the required antenna separation have restricted it principally to shore-based applications. With a range of less than 50 km, CODAR could not presently map the currents around Hibernia for example.

3.2 Water Depths

The depth of water at a given location is defined as the vertical distance from the sea bed to a datum that, in Canadian practice, is calculated from the tidal conditions over the survey area. The standard method of presenting water depths is the bathymetric chart showing contours of equal distance below the reference

datum. The objective in bathymetric surveying and charting is to obtain accurate depths at a sufficiently dense network of points to permit precise contouring. The only practical instruments to do this are echo sounders mounted in survey vessels. These sounders are acoustic devices which measure depth as the product of return travel time of a bottom-reflected signal and sound velocity in sea water.

In order to relate the sounding records to datum, the datum definition must be precise: this requires a good estimate of the tidal constituents over the survey area since these are used both to relate the instantaneous water level to datum during the survey, and to define the datum proper (Forrester, 1983). Tidal constituents are best obtained from water level recordings obtained at one or more points in the survey area (most accurate) or by inferring the datum and water levels from locations outside the survey area, usually shore stations (least accurate). The method of obtaining water depth is straightforward once the tidal information is known: depth equals the sounding minus the elevation of the water surface above datum, assumed to be predictable by the harmonic method (which is described in Chapter 4). The major sources of error are:

- uncertainity in the chart datum and the tidal data to reduce the soundings (vertical control),

- uncertainty in vessel position (horizontal control),

- inacurracy in the echo sounder and sounding trace digitization (removal of surface wave effects),

- inaccuracy in the sound speed calculation in sea water due to not having density profiles during the survey period, and

- sea bed mobility which may change depths.

The first two error sources are the most important. The Canadian Hydrographic service (CHS) believe their charts are accurate to within ± 10 cm for a very dense survey like that completed in 1981 - 1982 around Sable Island. Independent industry data suggest that this is optimistic and that ± 50 cm would be more representative. As one moves further offshore into deeper water, accuracies may be slightly worse due to a lack of tidal measurements, less accurate positioning information, less dense sampling networks and poorer echo sounder performance. Quantitative estimates of likely errors are not available.

Nevertheless, between the large-scale charts produced by the CHS and the small-scale surveys done by private contractors for the operators using similar instruments and procedures, it appears that bathymetric data are sufficiently accurate for exploratory purposes. Sounding instruments are not an area of concern.

3.3 Water Levels

Water level refers to the free surface elevation above datum. The usual procedure for measuring surface level is with a pressure sensing instrument mounted on the sea bed or some other fixed structure. Typical sampling intervals range from 15 to 20 min. to one hour. Accuracy of the pressure sensor is usually given as a percent of full scale range, with the consequence that accuracy decreases with increasing depth of deployment.

The measurement gives total pressure due to the hydrostatic head of the water column, which depends on sea water density and atmospheric pressure (roughly equivalent to a 10-metre column of water). Reduction of the water level data depends, then, on knowing the concurrent record of barometric pressure, its variation from the long-term mean pressure (inverse barometer effect) and the local water density structure. Inaccuracies in (or absence of) these data are reflected as inaccuracies in the resulting water level.

The reduction of water level variations to datum requires a harmonic analysis of the signal; from this a chart datum may be obtained (see Forrester, 1983) and used as a reference for the surface levels. This chart datum is related to the largest tides to be expected at the measurement site; it is not, however, an absolute datum invariant over all the areas of interest for exploratory drilling. Use of the chart datum is convenient since it also serves as the local datum for tidal predictions using CHS procedures (Godin, 1972; Foreman, 1977). This makes calculation of the instantaneous total water depth (barthymetric chart depth plus tide) straightforward and reasonably accurate.

The most commonly used water level recorders are those manufactured by Aanderaa Instruments Ltd. Sensor accuracies (0.01% of full scale) typically range from $\pm$ 0.03 m to $\pm$ 0.06 m for deeper water installations. Data are recorded on magnetic tape and generally processing of them is straightforward.

3.4 Water Property Measurements

There are only two water properties that are routinely measured -- temperature and conductivity. From these

parameters salinity, water density and sound speed are calculated by internationally accepted empirical relationships. Other water property data such as dissolved oxygen are determined from water samples rather than by in situ automated data logging.

Temperature is at present measured by resistive thermistors, although a variety of ingenious adaptations of classical thermometers were used in earlier days of oceanography. Thermistors vary in accuracy, precision and response characteristics; as a result, the end use of the data dictates the sensor selection. The same is true of conductivity sampling devices, whether they measure inductively or conductively. Inductive cells are more robust and common than conductive devices and less subject to problems of fouling and handling damage.

The application of dynamical oceanographic principles allows the inference of geostrophic currents from measurments of horizontal and vertical gradients in water density. To do so with confidence requires very accurate and rapid sampling of conductivity and temperature as functions of depth (i.e. CTD measurements). These data are collected in real-time by a profiling instrument dedicated to measuring conductivity, temperature and pressure. Typical accuracies are ±0.0002 mmho in conductivity and $\pm 0.01^{\circ}$ C in temperature.

For engineering purposes such as heat transfer rate estimates, corrosion studies or ballasting calculations this precision and sampling density of CTD data in unnecessary. Adequate data may be collected from thermistors and inductive cells incorporated in current meters that are deployed in accordance with government guidelines. As shown in Table 3.1, typical accuracies

for these devices are ±0.05° C in temperature and ±0.025 to ±0.05 mmhos in conductivity. Considerable degradation in the accuracy of salinity results if the response characteristics of the C and T cells are poorly matched when sampling in a rapidly varying environment. This situation arises when instruments are moored near a strong pycnocline which supports internal waves. Temperature gradients across the interface may exceed 10° C accompanied by salinity differences on the order of 1 ppt.

For some specialized applications, such as the detection of internal waves, temperature profiles at a site are required at a regular, fairly rapidly sampled interval. For this purpose self-recording thermistor chains are constructed with resistive thermistors wired at predeterminal depths. For internal wave detection, typical sensor separations could be 10 m with a one or two minute sampling period. These devices record on magnetic tape and are straightforward to process after instrument recovery.

4. ACCEPTED ANALYTICAL TECHNIQUES

In this chapter, generally accepted procedures for the analysis of oceanographic data are described. An effort has been made to reflect the fairly wide range of analysis procedures, and to evaluate the reliability of the conclusions reached with each method in terms of offshore design and operational requirements.

In order to understand and appreciate oceanographic methods it is necessary to realize that the ocean is a very undersampled environment and that oceanographers and engineers are frequently faced with the problem of drawing either general conclusions or long range forecasts from a very limited number of observations. A few years ago, when the goal of most oceanographic research was to understand the large-scale mean, or steady-state conditions, this undersampling was not as critical a problem since the relatively few measurements could be interpolated in time or space to provide a meaningful description of the appropriate oceanic properties. Increasingly, the demands for oceanographic interpretations are focused on the variability of the ocean in time and in space. For these studies chronic undersampling represents a significant challenge in producing reliable interpretations of the measurements collected. In addition, the demands for high volume, inexpensive data have rendered old collection methods obsolete by their inefficiency. Thus new measurement techniques are evolving to meet these challenges and with them new analysis procedures will need to be developed and evaluated.

All recorded values of oceanographic parameters must first be checked and edited to remove errors due either to instrument malfunction or to unwanted mooring motions.

Failures may be complete causing the entire record after the failure to be unreliable, or they may be sporadic. Most of these failures are related to sensor malfunctions, tape recording errors or low power supply. Occasionally instruments will fail to record one or a sequence of readings. This can be a very serious source of uncertainty in data from the Aanderaa RCM4 meters that do not record a time signature or time check with each sample.

Success in data editing is strongly tied to a good understanding of the individual instrument measuring and recording methods. Deletion of spurious data is sometimes achieved by objective methods based on the mean and standard deviation of the time-series; values exceeding two or three standard deviations of the mean are automatically replaced by linear or tensioned spline interpolation. A slower, but sounder method is based on visual inspection of the plotted signal by an experienced oceanographic data analyst who is guided by knowledge of expected variability, the characteristic signals of instrument malfunction, and understanding of sensor inadequacy.

For some applications such as harmonic or spectral analysis, the presence of a few data spikes is largely immaterial. For others like prediction of extremes, the spurious high values must be scrupulously deleted to have confidence in the results.

High frequency fluctuations occur naturally in the ocean mainly from internal waves propagating along the lower boundary of the mixed layer (the pycnocline). These waves are usually produced by storms. Other phenomena like current meanders or translations in oceanic fronts also induce variations in currents and water properties at certain locations. Instruments sample these rapid changes (from a few minutes to a few hours long), but these components of

the measured signal are usually removed by digital filtering to clarify longer-term trends. Some interpretative techniques (harmonic and spectral analysis, for example) require that these filtered data are further smoothed by subsampling to hourly values.

The relatively high cost of obtaining oceanographic data means that these observations are frequently extrapolated in space and time to generalize the characteristics for a particular region or season. In performing these extrapolations it is important to appreciate the quality of the orginal data, the initial screening or editing techniques and the methods used to extract information about certain physical phenomena. By being aware of the inherent limitations in the data it is easier to evaluate the validity of the conclusions based on them and to attach confidence intervals to any calculated currents.

4.1 Currents

4.1.1 Eulerian Measurements

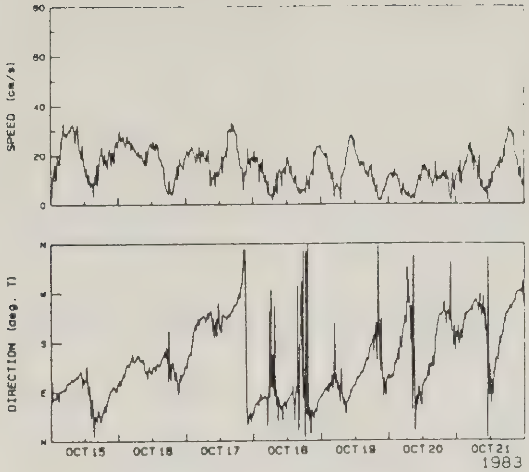
To study the variability of currents at a point, Eulerian current measurements are made with a moored instrument. The resulting data give a picture of the current as a function of time, but provide no information about spatial variations. Even in scientific field experiments, only a limited number of observation points are usually available concurrently, although most locations have instruments at more than one depth on the mooring line.

Time-Series and Simple Statistical Presentations

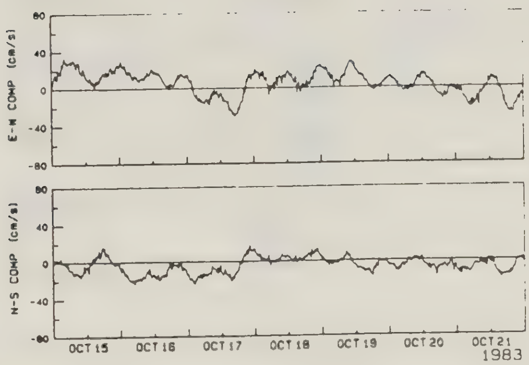
The resulting measurements may be presented in a variety of pictorial and statistical formats. They may be drawn

as time-series of current speed and direction (Figure 4.1a), as time-series of north-south and east-west vector components (Figure 4.1b), or as a series of scaled vectors representing the magnitude and orientation of the current as a function of time (Figure 4.2). This last type of presentation is useful in identifying general characteristics of the current series. For example, extreme currents appear as long sticks giving a visual impression of both magnitude and direction simultaneously. Regular variations in current flow appear as repeated sets of sticks; tidal currents, for example, evidence themselves as rotational events with a 12 or 24 hour period. Because of high frequency variations in current measurements, it is more common to plot stick diagrams of hourly or daily average currents than of the measured currents which are typically sampled at 1 to 20 minute intervals.

Another familiar graphical presentation of Eulerian measurements is a progressive-vector-diagram (PVD) which successively plots the current vectors end-on-end to demonstrate the progression of the current in time (Figure 4.3). As with the stick plot presentation both the extremes and characteristic variability of the current meter observations are readily apparent with this type of presentation. In spite of the plot layout, it is important to remember that it is not describing spatial variability, but rather each individual vector must be referred to the diagram's origin. A significant advantage of the PVD over the stick plot is its summary of the long-term trend in the data series. Since the current vectors are plotted end-to-end, the difference between the final end point and the origin represents the net current over the total observation period. Tidal and inertial currents are also well represented in the PVD and can be recognized by elliptical loops.



(a)



(b)

Figure 4.1 Time-series current meter data portrayed (a) as speed and direction, and (b) as E-W and N-S components.

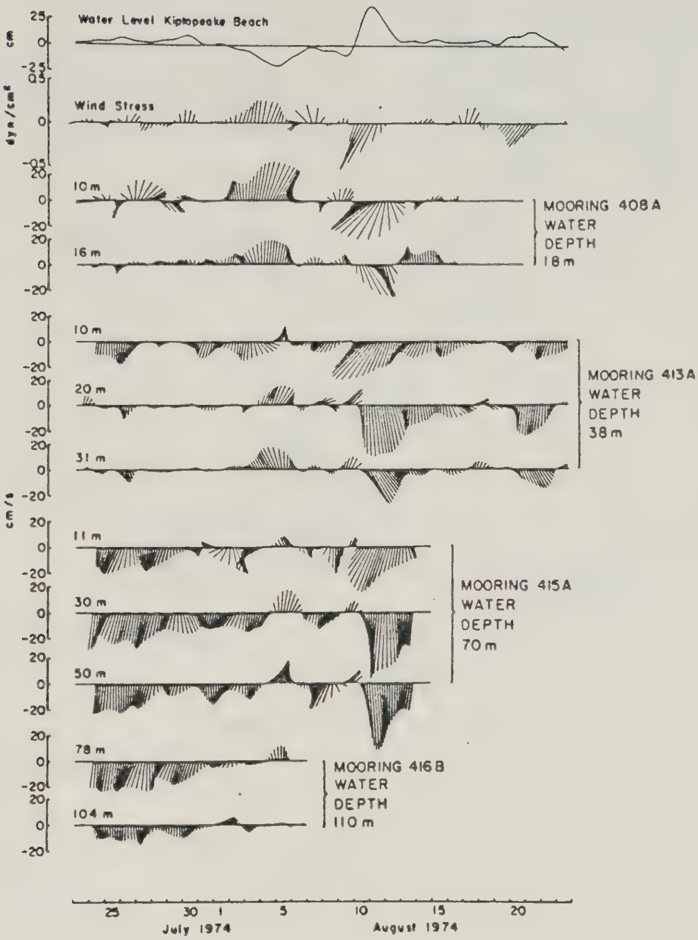


Figure 4.2 Time-series current data shown as vectors.

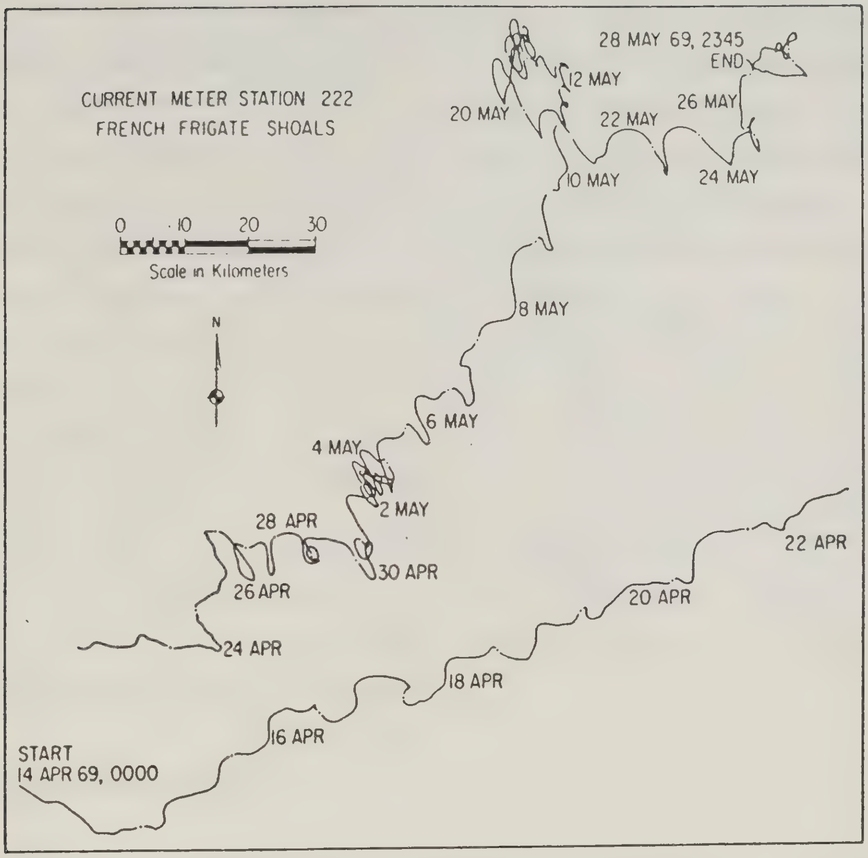


Figure 4.3 Progressive vector diagram of currents.

Each of these graphical presentations is useful for evaluation and interpretation of the general characteristics of the current field, but none of them contribute directly to the design process. For that purpose, time-series measurements must be reduced to statistical quantities that are suitable for extrapolation such as current speed exceedance, or that display some generality such as the directional distribution of current speed. Common statistical presentations are the bivariate histogram of current speed and direction (Figure 4.4) and its derivatives--the histogram of current direction (Figure 4.5 and the exceedance plot of current speed (Figure 4.6). These tables and plots readily provide descriptions of the general characteristics of the current (e.g. the most common current speed range, the predominant directions of high speed events, and the average speed). Persistence of current speed and of direction are two more representations that may be useful statistical descriptions.

The Mean Current

Perhaps the simplest quantity to consider is the vector mean of the time-series which represents the long-term average current. If the mooring time is less than a year or if strong seasonal current fluctuations are characteristic of the region, one must carefully select the period over which the average is calculated. Thus it is important in computing a quantity as simple as the series mean to consider the system being measured in conjunction with a prior knowledge of the annual variations of the system.

The relatively strong role of seasonal variations in most ocean currents precludes the use of short current meter records to estimate extreme currents representative of conditions for the entire year. This is true of the Canadian east coast where seasonal changes in the strength

Depth: 20 m 20 m
Sample interval 20 min
Sample period: 17/ 4/1982- 9/ 7/1982

Speed vs Direction

Dir. (Deg.)	Speed (cm/s) 0 to 5	5 to 10	10 to 15	15 to 20	20 to 25	25 to 30	30 to 35	35 to 40	40 to 45	NO. OF OBS.	% TOTAL	WEIGHTED AVERAGE	STD. DEV.
0- 15	64	66	25	13	3	2	0	0	0	173	2.9	8.	5.
15- 30	60	58	50	29	7	2	0	0	0	206	3.5	9.	6.
30- 45	62	78	44	24	9	3	0	0	0	220	3.7	9.	6.
45- 60	67	89	53	44	19	6	4	0	0	282	4.8	11.	7.
60- 75	79	85	58	41	28	11	8	4	0	314	5.3	12.	8.
75- 90	62	96	72	60	32	17	7	3	0	349	5.9	12.	8.
90-105	51	109	88	45	31	13	11	0	0	348	5.9	12.	7.
105-120	69	103	69	54	33	14	6	1	0	349	5.9	12.	8.
120-135	56	98	51	38	25	9	9	0	0	286	4.8	11.	8.
135-150	69	97	52	47	24	12	4	2	1	308	5.2	11.	8.
150-165	83	72	36	34	16	8	6	2	1	258	4.4	10.	8.
165-180	54	77	37	27	8	6	1	3	0	213	3.6	10.	7.
180-195	56	67	31	26	12	4	8	0	0	204	3.5	10.	8.
195-210	64	69	31	17	9	5	5	1	0	201	3.4	9.	8.
210-225	66	72	39	20	8	9	7	0	0	221	3.7	10.	8.
225-240	66	66	38	23	6	6	6	1	0	212	3.6	10.	8.
240-255	80	64	55	17	8	6	3	4	1	238	4.0	10.	8.
255-270	66	84	62	28	18	5	0	1	5	269	4.6	11.	8.
270-285	56	92	79	34	20	8	2	5	1	297	5.0	11.	8.
285-300	61	83	49	20	8	1	0	2	0	224	3.8	9.	6.
300-315	51	61	43	20	5	4	1	0	0	185	3.1	9.	6.
315-330	71	83	34	8	5	2	0	0	0	203	3.4	8.	5.
330-345	71	69	27	6	4	3	0	0	0	180	3.0	7.	5.
345-360	50	74	28	9	2	1	0	0	0	164	2.8	8.	5.
SUM	1534	1912	1151	684	340	157	88	29	9	5904			
% EXCEED	74.0	41.6	22.1	10.6	4.8	2.1	0.6	0.2	0.0				

Figure 4.4 Bivariate histogram of current speed versus direction. The table gives the number of observations in each interval.

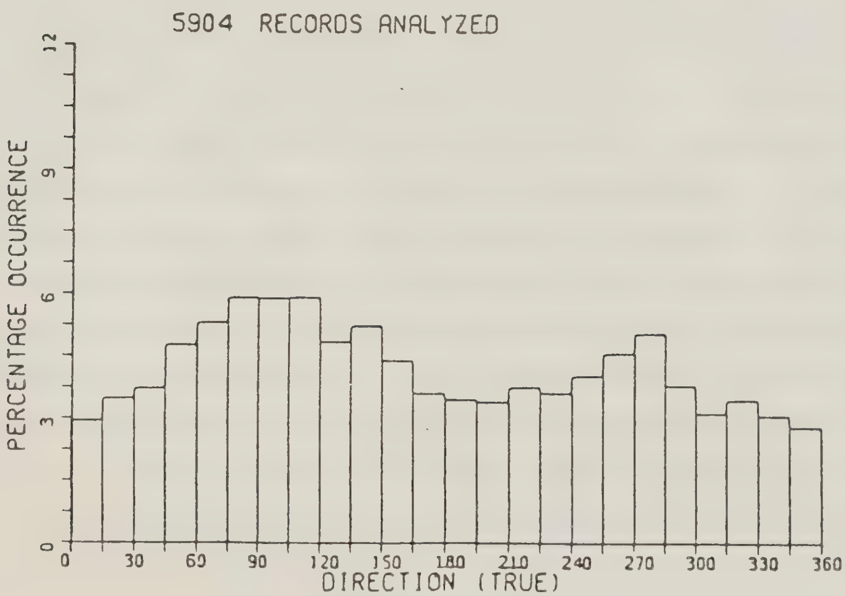


Figure 4.5 Frequency histogram of current direction.

and position of the Labrador Current limit the usefulness of short current meter records. It is particularly inappropriate to infer winter currents from summer data series. In winter the wind input and atmospheric cooling usually lead to dramatic changes in the ocean structure and circulation.

Spectral Analysis

All measured currents are composed of constituents with differing temporal scales of variation: inertial currents, diurnal and semi-diurnal tidal components, and low frequency geostrophic motions for example. To assess the relative importance of the various components, it is customary to isolate them based on frequency-domain analyses that compute energy spectra.

Since both tidal and inertial currents have preferred directions of rotation, it is becoming common practice to compute rotary spectra which yield statistical estimates of the energy associated with both clockwise and counterclockwise rotating current fluctuations. A rotary spectrum, such as the sample shown in Figure 4.7, may be useful in distinguishing the inertial peak from the tidal variations since the inertial flow must be clockwise in the northern hemisphere. Although rotary motions can usually be identified in the time-series vector plots (e.g. Fig. 4.1c), the advantage of the rotary spectrum is that is clearly isolates these time scales of motion from others which can mask them.

Harmonic Analysis

Spectral presentations of currents aid in interpretation of measurements, but they do not play the important role in engineering analysis and design that wave spectra do.

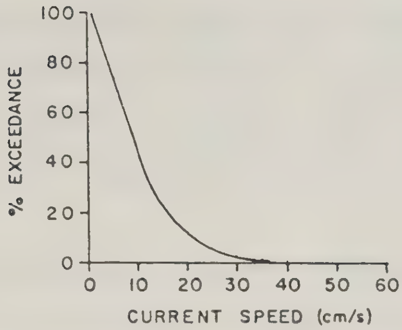


Figure 4.6 Exceedance plot of current speed.

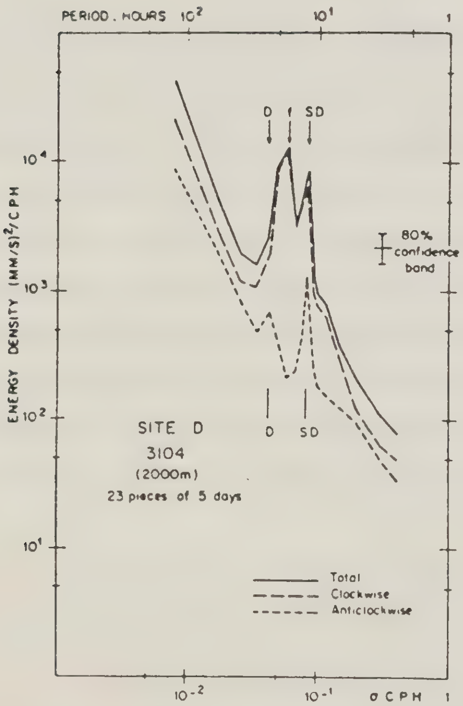


Figure 4.7 Rotary spectrum of currents showing the diurnal (D), inertial (f) and semidiurnal (SD) peaks.

This is so because the tide, which often represents 30 to 50 percent of the total current, is a predictable quantity. Since the tides are driven by known periodic motions of celestial bodies, a great many tidal constituents have been computed and the corresponding frequencies have been determined very precisely.

Harmonic analysis is a curve fitting procedure which estimates the amount of energy in a signal that is associated with each of the fixed tidal frequencies. The method assumes that the tidal current results from the linear combination of the individual harmonic constituents. In practice, only 5 to 10 of the tidal components are required to adequately approximate the tidal currents and these can be quite accurately determined for a site from just a few weeks of current measurements.

Since harmonic analysis of a relatively short current record computes both the amplitude and phase of the tidal components, it is straightforward to predict the magnitude and direction of the tidal current at the measurement site for many years. For offshore operators this information can be very valuable -- to schedule diving and BOP installation when tidal currents are at a minumum, to optimize iceberg towing, or to anticipate internal waves. For design purposes, it means that the maximum tidal velocities can be obtained with certainty.

The precision of tidal predictions is diminished in shallow water since the tide is no longer truly barotropic, but is reduced near the bottom due to friction. Consideration of the non-tidal current structure is also important in shallow water since complex interactions between those currents and the tide may result but are not accounted for in linear harmonic analysis.

Another important consequence of accurate tidal prediction is that the non-tidal signal can be readily extracted from current measurements by simple vector subtraction. This procedure is now the recommended method for separating tidal and inertial signals and supercedes digital filtering techniques (e.g. Godin, 1972). For predictive and hence design purposes, this separation is essential and must be done carefully, particularly for sites between approximately 68° N and 80° N latitude where the inertial and semi-diurnal frequencies are almost equal. On the East Coast, this applies to Lancaster Sound, Baffin Bay and the northern half of Davis Strait.

4.1.2 Lagrangian Currents

An alternative way to measure ocean currents is the Lagrangian approach of tracking a parcel of water, although the coupling between the water parcel and its "follower" is usually not well-established. With satellite tracking technology, the use of following floats and drifting buoys has become a feasible method of obtaining currents information over large, often remote areas of the ocean. The buoys can be equipped with batteries to last about a year, and in addition to reporting their position, they can also transmit *in situ* measurements such as atmospheric pressure and sea surface temperature for input to numerical weather forecasting models.

Surface drifter cards have been used to simulate the dispersal of oil on the sea surface. They are normally tracked by aircraft and the data collected are concentrations of drifters rather than individual trajectories.

This Lagrangian view of the ocean current doesn't lend itself to the usual types of current data analyses used with Eulerian measurements. The present standard practice in the presentation of Lagrangian trajectory data

is to plot all the tracks on the same diagram (Figure 4.8). The patterns presented by a collection of platform trajectories are frequently very confused, and the resulting plot is sometimes referred to as a "spaghetti" diagram for obvious reasons.

Assuming that the buoy or float is properly coupled with the ocean, the data analysis must account for both temporal and spatial changes that are inherent in Lagrangian data. In spite of the dual nature of these observations, there are some conventional analysis techniques applied to Lagrangian data. Rather than using the original unevenly spaced data, the Lagrangian trajectories are usually interpolated to a data series with an even interval such as daily values, which are then used to compute velocities from the displacements between them. The resulting current vectors can be mapped on the region travelled by the buoy as illustrated in Figure 4.9.

Using these daily values, investigators have computed parameters such as vorticity, dispersion, or vertical current shear based on different drogue depths and horizontal current shear. In addition to being used to describe the mean circulation, RMS variations in buoy velocities have been used to estimate the kinetic energy associated with mid-ocean mesoscale eddies.

The interpretation of quantities measured by the floating buoys suffers from the problem of separating time and space variations. In some applications this is of little consequence. The weather service, for example, deploys buoys instrumented with atmospheric pressure sensors to return samples of open ocean atmospheric pressure. These data are simply taken at the time and position reported and included in maps of sea level pressure. Since they

Figure 4.8 Composite trajectory plot of drifting buoy data (source: Osborn et al., 1978).

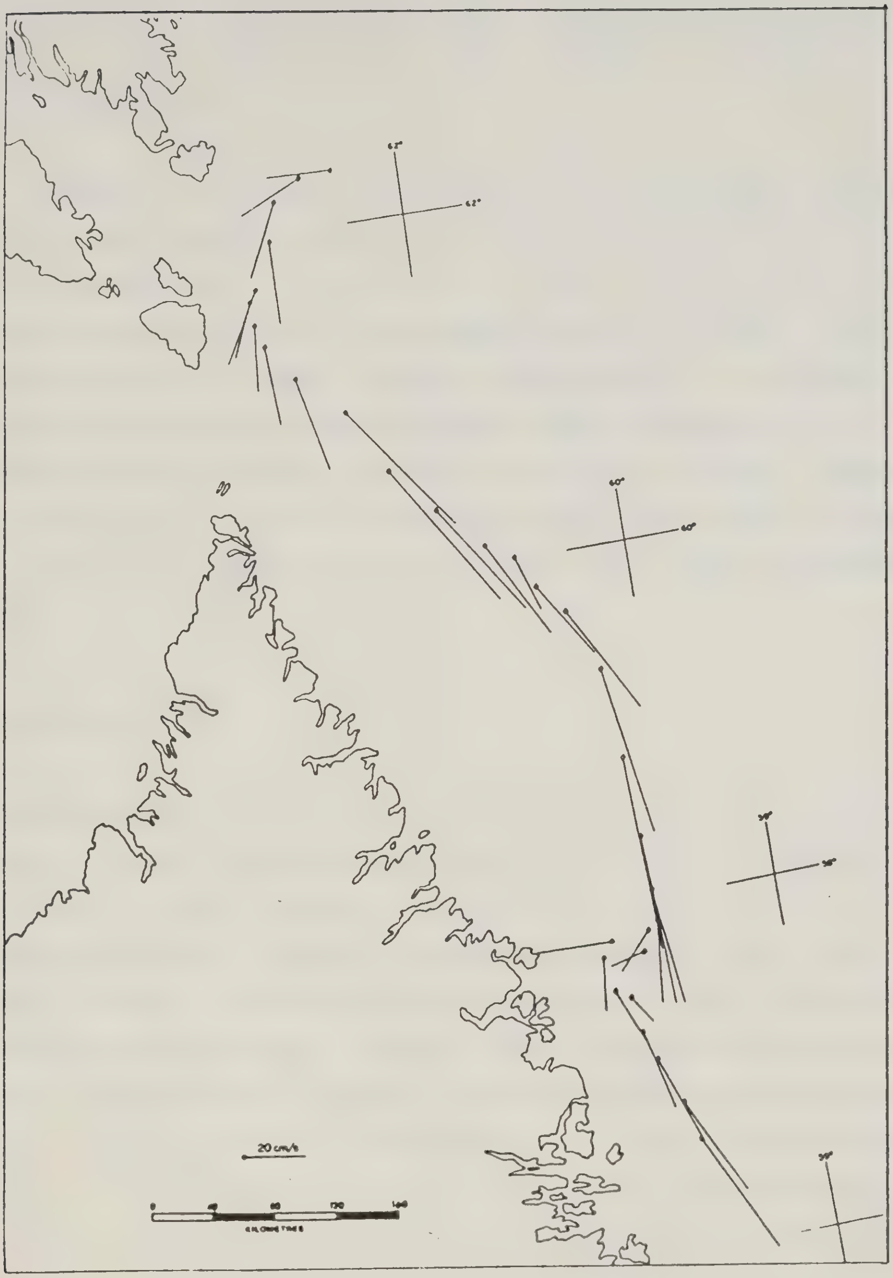


Figure 4.9 Daily averaged drift currents calculated from a buoy trajectory.

are deployed along routes not frequented by ship traffic these buoys add valuable data points to maps of atmospheric pressure.

In summary satellite-tracked drifting buoys offer a unique automated way of collecting trajectories of ocean currents. In spite of the problems in using the resulting data for the computation of ocean current properties the buoy trajectories yield a straightforward picture of the current speed and direction in an area. Reported by satellite these drifting buoys represent a technology that can provide supporting data without a significant added input in terms of ship or personnel time.

4.2 Water Levels

Fluctuations in coastal sea level were first measured in an effort to understand the 12 and 24-hourly variations in water level called the tides. If accurately referenced to a local landmark height these sea level data can be used to study more than just tidal water level fluctuations. Long term changes may be associated with atmospheric climate changes which alter the temperature and salinity of the surface layer of the ocean and thereby affect its water level. At time scales of hours to days phenomena such as storm surge build-up and continental shelf waves can be observed in sea level height. Usually short time scale fluctuations due to surface gravity waves are damped out of the measurements by the design of the water level response system.

In studies of tidal variations the sea level data are analyzed using time-series methods to identify the amount of energy associated with the known tidal frequencies. Since tidal forcing mechanisms are well understood and

the periods of the forcing terms (called constituents) are well established it is often most convenient to use harmonic analysis techniques. This procedure fits the observed data with the known constituents thus determining the amount of the measured variability associated with each.

Conventional spectral methods are reviewed for tidal analysis in a book by Godin (1972). Using Fourier transform methods the time-series of sea level heights are used to calculate a spectrum which will then have sharp peaks at the known tidal periods. From the relative sizes of these peaks, it can be decided how much of the observed variance is associated with each of the tidal constituents and hence which of them are most important for the location being studied.

The spectral method has the advantage that sea level variations, at periods other than those corresponding to the tides, also show up and their importance can be inferred from the spectrum. Since the periods of most importance in these data are well known (the tidal periods) digital filters can be designed to bring out these periods while suppressing variations at other time scales. The same technique can be used to suppress the tides if non-tidal sea level variations are of interest. It is important to realize that only statistically significant peaks can be used to distinguish differences in tidal behaviour and that most peaks in simple periodograms are usually not significantly different from each other.

Whether using spectral techniques or harmonic analysis one goal of conventional tidal studies is to estimate the magnitude and phase of the significant tidal constituents.

Once known, this information can be used to predict tidal heights for the future at and near the measurement location.

The other goal is to extract the non-tidal signal, principally storm surge, for statistical extrapolation that provides input to design calculation. This is readily done by subtracting the estimated tidal time-series from the total measured signal. The tide can be estimated by harmonic analysis as described above, but traditionally the tidal signal has been removed by the digital filtering recommended by Godin (1972). This is the technique used by the Marine Environmental Data Service, for example.

4.3 Hydrographic Measurements

Temperature and conductivity, from which salinity and density are calculated, are routinely measured by the near-surface, mid-depth and near-bottom current meters deployed for regulatory compliance by offshore operators. These are time-series data which are normally plotted along with the other current meter parameters. The extent of interest in these data is to obtain representative values of their extremes, means and variability. This is usually quite sufficient for routine design considerations like heat loss and non-critical buoyancy calculations.

For other design purposes such as the estimation of maximum likely wind-driven currents, much more detailed information on the vertical density structure is required. This is obtained from hydrographic profile measurements of conductivity, temperature and depth (CTD). Modern CTD's generate a large number of data values as they transit the water column due to the fast response times of the individual sensors and the data handling circuits. The full resolution data densities are only required for studies of phenomena such as turbulence and small scale

mixing. For most purposes so many data values are not essential and the recorded data are subsampled to yield a lower resolution but workable sized data file. When resampling, consideration must be given to the physical mechanisms being studied in order to properly select the appropriate sampling interval. Resampled data may be calculated by sequential or moving averages to reduce the vertical resolution or by interval sampling of the original data. The former technique is less subject to aliasing effects and should produce smoother lower resolution data.

Another useful derived parameter which is calculated from the density is a vertical stability parameter such as the Brunt-Väisälä frequency which is proportional to the first derivative of the density with depth. Not only does this parameter indicate the static stability of the density distribution but it is also a frequency limit for local internal waves that rely on the density structure for their existence.

The most valuable quantity computed from hydrographic data, in terms of water movements and currents, is the dynamic height. Computed as the integral of density over depth, the dynamic height is an estimate of the internal pressure field in the ocean. Due to the rotation of the earth and the resultant Coriolis force, the pressure gradient is in balance with this Coriolis force and the resultant currents are known as geostrophic currents. It must be emphasized that these geostrophic currents represent a balance of forces and not a cause and effect relationship. Even with this limitation it is a method by which oceanographers can estimate at least part of the ocean current from routine measurements of temperature, salinity and depth.

Since these currents are produced by the pressure gradient force the computation of geostrophic currents requires at least two measurement stations to compute the current. Normally a set of stations is used to map the dynamic topography from which the currents are inferred as gradients of dynamic height. An example of such a map is given in Figure 4.10 for the Canadian East coast. Based on a relatively few hydrographic stations this current map has proved to be remarkably consistent with the findings of later studies regarding the flow directions of the mean currents. Thus the computation of geostrophic currents from easily made observations of temperature and salinity provides a powerful method to estimate ocean currents without the need for direct measurements of current speed and direction. It is generally assumed that the geostrophic currents depict currents which vary slowly in time and are part of the long term circulation pattern. They have, therefore, been calculated and added to predicted tidal currents, and extrapolated wind-driven currents to provide estimates of the total design current regime.

4.4 Dissolved Oxygen

Unlike temperature and salinity, dissolved oxygen in the ocean is considered as a non-conservative property. This means that it may be either created or consumed within the water column in addition to primary input at the sea surface. In biological exchange dissolved oxygen may be created through photosynthesis by phytoplankton or used up by the zooplankton in the upper layers of the ocean. Chemical reactions also can consume dissolved oxygen by the oxidation of organic material as it falls through the water column.

The most important role that dissolved oxygen plays in coastal regions under offshore oil development is in its

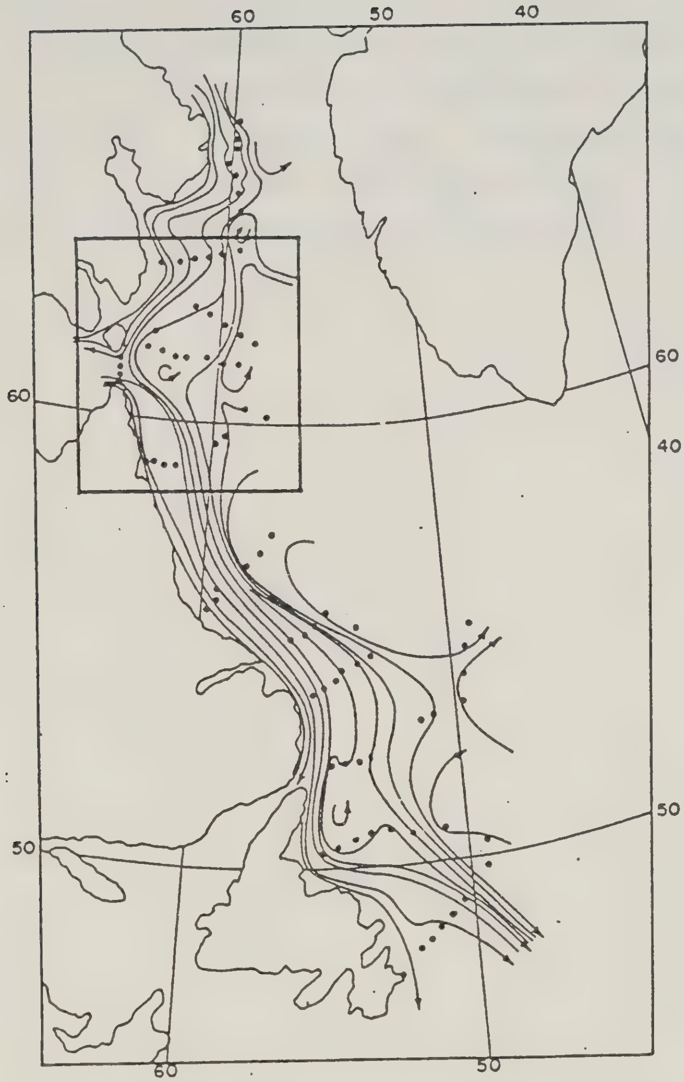


Figure 4.10 Map of dynamic topography obtained by Smith et al. (1937) from the CGC MARION Expedition.

link to biological activity. Its addition to the water column is a signal of primary (phytoplankton) productivity while it also must be present for the successful operation of the zooplankton community. Thus any activities that will lessen the availability of dissolved oxygen will impact on the plankton coummunity. There may be important chemical factors from drilling operations that may inadvertantly lower the amount of available dissolved oxygen.

5. ACCEPTED PREDICTIVE TECHNIQUES

In the most general sense, predictive techniques, or 'models', are required for oceanographic parameters to meet two different demands. On the one hand engineering design criteria are needed for drilling unit design or selection; these criteria are concerned with rig survival under extreme conditions and the problem is one of long-term prediction of the worst currents, water levels and, perhaps, water temperatures to be expected at a given site. On the other, operational criteria are needed to plan drilling programs, to organize and execute ice and oil spill countermeasures, and to carry out search and rescue missions as the needs arise. The problem here is one of short-term temporal, and spatial extrapolation to define 'normal' oceanographic conditions. A useful distinction between normal and extreme criteria can be made in terms of the engineering concept of return period: normal conditions have a return period of one year or less, i.e. they can be expected to recur every year or season during which drilling will take place. Extreme conditions are those having 50 or 100-year return periods i.e. they are expected to occur only once every 50 or 100 years.

Before dealing with specific oceanographic parameters three very general catagories of predictive models will be described. In terms of increasing demand for field data for their operation and validation these are:

1) Probabilistic models - most familiar to engineering analysts, these models make use only of time-series measurements of the parameter of interst to construct cummulative distribution functions. Parameter values at any specified exceedance may then be calculated from these distributions. This approach removes all physical considerations from the problem and relies solely upon the statistical properties of the data. It is most often used to estimate extreme values.

2) Empirical models - these are based on establishing relations between the response of the ocean (for example, currents) and the factor or factors causing the response (for example, the wind). They are predictive in the sense that if one knows the forcing conditions for a given situation then one can calculate the response directly. Applications include both normal and extremal conditions, and design of these models may involve physical considerations.

3) Deterministic models - are based on theoretical physical principles and a detailed parametric description of the ocean; parameters would normally include bathymetry, density, temperature, salinity, water currents and winds, either together or in some reduced subset. Depending upon their complexity, these models require a great deal of data to initialize and solve.

All of the above are mathematical models; physical scale models are seldom, if ever, used to predict oceanographic conditions due to difficulties in determining suitable scale factors and the cost of constructing and controlling appropriate facilities. They are, however, widely used to

study the response of drilling units to extreme waves (naval architecture); the present state-of-knowledge on ocean wave conditions for the Eastern Canadian offshore is discussed in a separate report by Wilson and Baird (1984).

5.1 Currents

Of all the oceanographic parameters that potentially affect an offshore drilling operation currents are by far the most important. At a particular location the total flow can be regarded as a superposition of current components arising from different forcing mechanisms. High frequency currents, the components that fluctuate more rapidly than the tidal currents, are mainly due to oceanic turbulence, wind waves, or internal waves. The major tidal currents arise through the gravitational attractions of the moon and sun and fluctuate over periods of within a day (the durinal period) or half a day (the semi-durinal period) to a fortnight. The third component, overlapping with tidal currents, represents fluctuations having periods longer than the semi-diurnal tidal period and less than about a month or so. Since this component of circulation is caused by the stress or the wind on the sea surface it will be refered to as the wind-driven component. The seasonal currents, designated as a fourth current component, refer to currents fluctuating over periods longer than about 30 days. This component arises from seasonal changes in the prevailing winds and from seasonal variations in the strength of the density driven currents.

In establishing predictive models for currents, then, one must deal with the question of the extent to which these components can be treated separately. It is attractive

in formulating some deterministic models, for example, to deal with one or two components distinct from the rest (usually tides or wind-driven currents at the inertial frequency); this simplifies the formulation and the data required for input. The difficulty occurs when attempting to recombine the components in a probabilistic framework for estimating extremes since then one must examine the joint probability arising from the recurrence of the individual components.

The simplest approach to estimating design currents is through the cummulative distribution of speed obtained by fitting a function to measured data. The approach is analagous to probabilistic models used for extreme winds. Like wind, the current is a vector quantity, and this property is usually recognized by deriving distribution functions in a number of directional sectors. Because the tidal currents can be predicted at any future time with good confidence by knowing the harmonic constituents, it is normal to remove the tidal currents from the measured data and construct the probabilistic model on the non-tidal, residual signal. An adequate tidal analysis requires at least 30 days of continuous data; this is not, however, an important limitation on the method since confidence in the probabilistic model results depends strongly on having data spanning many years. A general guideline states that one should not extrapolate much beyond two or three times the database length: for 100-year return extremes this rule demands 30 to 50 years of measurements, a condition not met by any data now available in offshore regions.

Like wind wave hindcasting, empirical current modelling attempts to overcome the limitations imposed by short time series of measured currents by taking advantage of

the much longer wind database. In this approach it is assumed that the wind-driven currents can be related to time series of wind measurements from one or more meteorological stations. These stations need not be located only at the site of interest. The possibility exists that the measured currents can be generated by wind forcing at large distances (>1000 km) from the measurement site. Robinson (1964) showed theoretically that the continental shelf can act as a waveguide for shelf waves. These shelf waves, which can have wavelengths of the order of 1000 km, are important for determining how waters on the continental shelf respond to wind forcing (Gill and Schumann, 1974), and provide a mechanism for transporting kinetic energy imparted to shelf waters by the wind over great distances. Brink (1982) and Webster (1983) have shown that a major part of the wind-driven currents on the shelves of Peru and North West Australia are for example, due to wind forcing more than 500 km away.

The first step involves a coherence analysis between winds (inputs) and concurrently measured currents (output). To test for significant relationships the coherence analysis is performed on the output and each input taken in turn. These analyses are done in the frequency domain since the current response to wind forcing is expected to be frequency dependent on theoretical grounds. The significance of the coherence relationship between a given input and the output can be judged using established statistical formulae.

Using the set of inputs significantly coherent with the output, a multiple coherence analysis (Bendat and Piersol, 1971) is performed next. If some portion of the output is expressible as a linear sum of the inputs then this procedure provides a functional relationship between

current and wind. Applying this relation to historical wind data provides a long-term time series of estimated currents. This expanded time series can then be used to estimate extreme currents using the probabilistic approach.

Data required to derive empirical models include accurate over-water time series of measured wind and simultaneous currents. If the lowest frequency variations retained in the analysis have periods of the order of one month, then roughly 10 to 15 months of data are required to establish the multiple coherence function reliably. Atmospheric pressure may also be used in the absence of wind data, but as Adams and Buchwald (1969) have shown wind and wind stress are more efficient current generators than changes in atmospheric pressure. Then the coherence may be weaker with pressure and hence less reliable for estimating currents.

The obvious limitations on the method is that it treats only the wind-driven motion, neglecting the density-driven flows. In certain areas, directly in the stream of the Labrador Current, or the Baffin Current further north (LeBlond et al., 1981), for example, this may fail to account for 25 to 30 percent of the total current; elsewhere, the neglected flows would likely have a much smaller contribution. The attraction of empirical modelling is that at certain locations, particularly near Hibernia and Sable Island, sufficient data now exist to apply the method, and in principle, it should yield better extreme current estimates than can be obtained directly from the measured data.

The above methods focus on the problem of extrapolating currents in time to derive extreme value estimates at one location; they provide no information on spatial

variations in currents between two or more locations. Because the continental shelf bathymetry plays such an important role in steering currents and modifying the tides, predictive techniques that seek to model 2 or 3-dimensional flow characteristics must explicitly incorporate the bottom features. For internal tidal, wind-driven and density-induced flows the water column stratification must also be taken into account.

These effects can only be introduced into deterministic models, which in general are based on differential equations describing the conservation of mass, momentum, or vorticity in the flow field. In simplified cases, some analytic solutions can be found but these are seldom applicable to oceanic problems. Recourse is then made to numerical procedures implemented on large computers. Models differ greatly in complexity from "point-models" for wind-driven currents (Ekman, 1905; Pollard and Millard, 1970; Pollard et al., 1973; Kraus, 1977) to depth-averaged tidal models (see e.g. Abbott et al., 1973), to full 3-dimensional models that attempt to simulate the combined effects of wind and tidal forcing, and density-driven flows (see Leenderste and Lui, 1975; and Lui and Leenderste, 1981).

The point models provide no spatial information but depend on having reliable data on vertical strafification for their accuracy. As discussed in the next chapter much water property data has been collected and archived, particulary over the Grand Banks and Scotian Shelf. These data yield statistical descriptions of changes in stratification with season; they are somewhat less useful for estimating the strongest stratification likely to occur at a given location. This becomes important for extreme wind-driven currents since maxima near the surface

will occur with storms at times of intense stratification. We note the existence of four excellent regional data sets: one collected in 1976/1977 by Esso Resources Canada Ltd. (Osborn et al., 1978; LeBlond et al., (1981) in Davis Strait, one collected by Petro-Canada in 1979/1980 in Lancaster Sound (Fissel et al., 1982), another collected by Petro-Canada along the Labrador Coast in 1980 (Fissel and Lemon, 1982) and the fourth collected by Mobil on the Grand Banks in 1980. Each dataset was obtained with profiling instruments at systematically distributed points in intense measurement campaigns. These data likely give the most reliable picture of stratification during ice-free periods for each region. Away from the Grand Banks, Scotian Shelf and these four survey areas the data are sparse.

One special type of two-dimensional modelling has been done for many East Coast areas and provides valuable insight into the general circulation patterns. This involves the mapping of geostrophic currents, using dynamical oceanographic principles, over large scales (e.g. the Labrador Coast). The predicted currents represent a portion of the net flow in an area, and if current meter or drifter data are available to "calibrate" these maps, a good estimate of the total residual circulation can be made. The current fields obtained this way are fundamentally important to long-range ice or oil spill drift prediction because they provide information on spatial variations in currents over large distances.

The basic data required to construct geostrophic current maps consist of a dense network of hydrographic stations giving profiles of water density. To be useful the stations must be sampled over a period well below that over which seasonal water mass changes can take place.

Although resolution is limited with this method, depending upon the density of sampling stations and the data averaging techniques used, it reveals circulation features with dimensions of the order of 50 to 100 km. It has no applicability, however, for predicting the spatial details of flows immediately around drilling rigs.

More elaborate two and three-dimensional determininstic models require yet more data to run. Bathymetry data are needed on a grid of points, but this usually does not present a problem because the shelf areas are sufficiently well charted. Hydrographic data (water temperature and salinity) and current and water level data are required throughout the grid to initialize the solution, and along the grid boundaries as functions of time to drive the model. Where wind is included the surface wind stress is also needed, as a function of time, over the grid. In general all these data are never available and this level of modelling is not a practical alternative to support drilling operations in the study area.

5.2 Water Levels

Changes in water level produced by tides and storm surges are important near coastlines (e.g. Bay of Fundy, Gulf of St. Lawrence, Ungava Bay-Hudson Strait and the Labrador-Baffin Island inlets) and around Sable Island. They can effect the design of jackup drilling rigs in two ways: first, directly, as the maximum water levels produced by wave, tide and surge add to give a design value for airgap, and second, indirectly, as the water depth influences the form and maximum height of shoaling wind waves (around Sable Island in particular).

Prediction of maximum water levels caused by tides is best done by the harmonic method for locations where the constituents are known. In coastal areas tidal water levels are strongly dependent on the surrounding topography, and numerical deterministic modelling is routinely carried out to, in effect, interpolate along the coastline between points of known tidal variation. This type of modelling becomes less accurate away from the coast because the required tidal input data are not often well known along the open-sea model boundaries. Storm surge levels may be derived by each of the modelling approaches discussed above. Again where good long-term measurements exist (confined to the coastline in Eastern Canada) probabilistic models based on the detided residual water level signal can be used with success. The most common alternative is deterministic modelling, usually driven by wind fields derived by techniques similar to those used for input to wind wave hindcasting models.

5.3 Water Properties

Information on water temperatures, salinities and densities is usually derived using simple statistics to give some idea of the parameter ranges, means and standard deviations. These are done on a time basis (most often monthly) which will reflect seasonal changes. This is particularly important for surface waters in the Eastern Canadian offshore since changes due to the winter ice cycle, the summer melt-water run off and solar insolation strongly influence water properties.

In principle, the type of three-dimensional deterministic current modelling discussed above would provide data on water property distributions. However, the basic input data to drive these models is not available with sufficient precision to make the approach worthwhile.

6. SOURCES OF PHYSICAL OCEANOGRAPHIC DATA

It is clear from the preceding discussion that all of the models used either to derive long-term design criteria or to spatially interpolate currents or water mass properties require oceanographic data. In this chapter sources of these data are reviewed and the extent of data coverage for the Eastern Canadian offshore is illustrated. This is used as a basis for commenting on the viability of predictive techniques for oceanographic parameters.

Coastal data holdings have not been included in this survey because they are not particularly relevant to hydrocarbon exploration.

6.1 Data Sources

The pertinent oceanographic parameters include surface and subsurface currents, water levels and depths, water properties (temperature, conductivity, salinity, dissolved oxygen concentration) as well as evidence of internal waves and biofouling. The primary data sources are discussed below, together with the types of data generally available from each particular source.

6.1.1 Industry

Companies drilling exploratory wells off Eastern Canada have from the earliest days of such exploration in the late 1960's, made numerous oceanographic measurements, concentrating particularly on subsurface currents and bathymetry. The bathymetric data were typically collected as part of the series of surveys undertaken on offshore tracts to determine a precise well site location. Seldom, however, were current measurements obtained before actual drilling began. Until 1978,

most current measurements collected by exploratory operators were recorded from instruments lowered to one or two specified depths from the drilling platform. In the past five years it has become customary (and is now dictated by federal guidelines COGLA, 1983) to deploy and maintain subsurface current meter moorings in conjunction with drilling operations. As a result the amount and quality of industry-sponsored current meter data has grown substantially in recent years. Sea surface temperature data are also collected as part of the routine three-hourly observations.

Large systematic oceanographic programs have also been carried out by industry as part of baseline studies for environmental impact assessments. These have been regional in scope and consisted of integrated sampling of many parameters. The major studies to date have been:

- the 1976 - 1977 physical oceanographic study in Davis Strait and the mouth of Hudson Strait (Osborn et al., 1978) conducted by Imperial Oil Limited.

- the 1978 - 1979 study of Lancaster Sound and Western Baffin Bay (Fissel et al., 1982) undertaken by Petro-Canada.

- the 1980 offshore Labrador oceanographic study undertaken by Petro-Canada which resulted in approximately thirty moored current meter records and about 300 conductivity/temperature/depth profiles (Fissel and Lemon, 1982); and

- the 1980 Grand Banks shipboard oceanographic survey conducted for Mobil Oil Canada, Ltd. in which hydrographic stations were occupied on a year-long series of twice monthly biological survey cruises.

In each of these programs many water property samples were collected; the distributions of sampling stations are shown in Figure 6.1 to illustrate the spatial coverage that was achieved. Figure 6.2 shows temperature cross-sections from Davis Strait to illustrate the water mass structure that can be deduced from the survey data.

More specialized studies have also been undertaken as needs arose. These include:

- the measurement of currents and water properties associated with internal solitons in Davis Strait (Hodgins and Westergard, 1981) by Canterra Energy Ltd.;

- deployment of drift cards in experiments conducted by C-CORE and by Bedford Institute of Oceanography from Mobil Oil Canada, Ltd. rigs on the Grand Banks.

It is fair to say that the contribution of data by industry has substantially improved knowledge of the oceanography surrounding the offshore leased lands. The situation would be immeasurably more difficult if one took away data collected by the operators, particularly the large regional surveys.

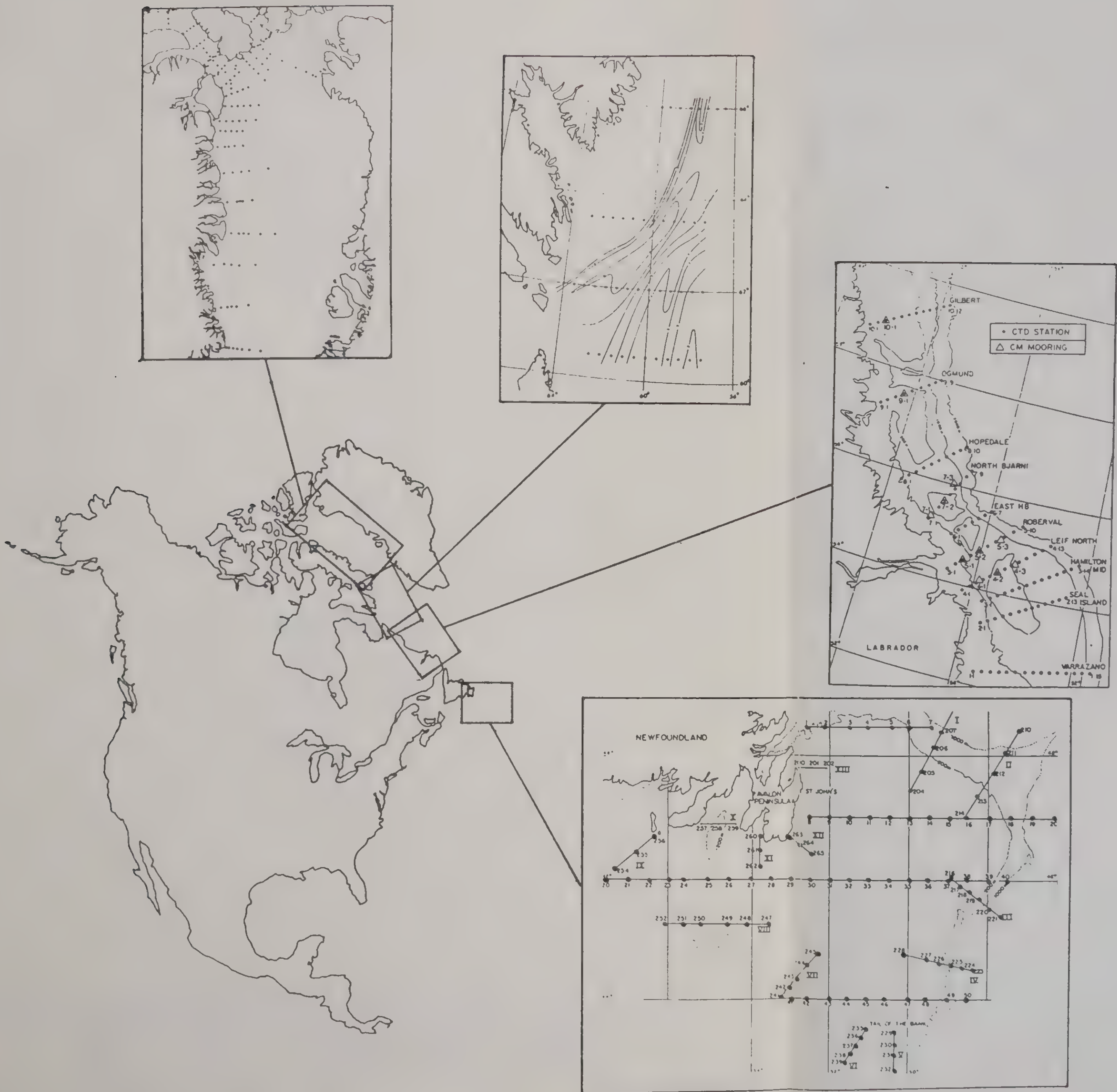
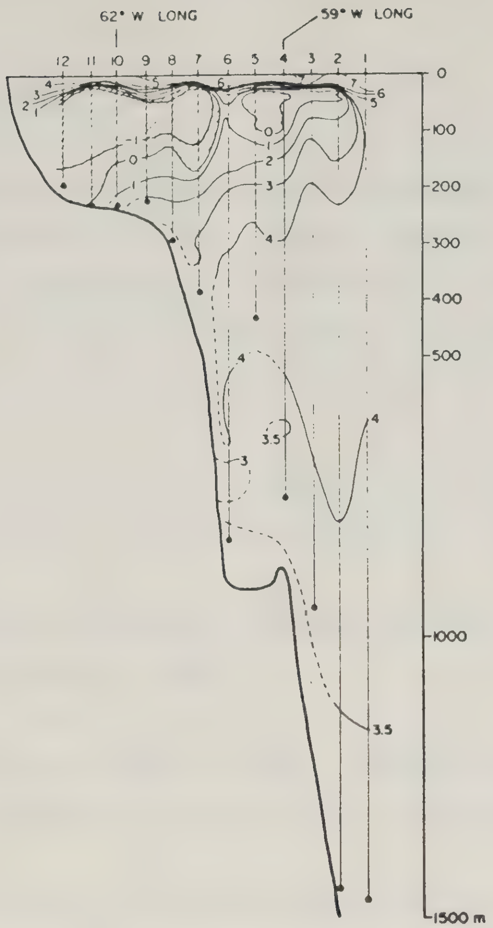


Figure 6.1 Distribution of water property sampling stations for industry-sponsored regional studies.



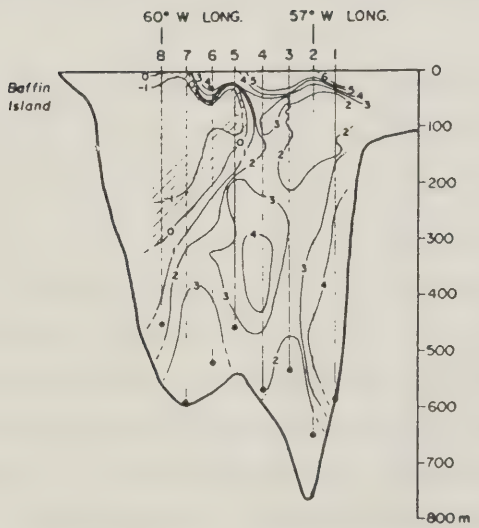


Figure 6.2 Temperature cross-sections in Davis Strait illustrating the water mass structures associated with the Baffin Current (Osborn et al., 1978). These sections are plotted using temperature-depth profiles sampled along two of the lines shown in Figure 6.1(b).

Seaconsult

6.1.2 Federal Government

Through numerous agencies the Canadian Government has been responsible for the collection of large amounts of physical oceanographic data of all types. Archives of historical data include major contributions from the following Bedford Institute of Oceanography agencies:

- Atlantic Oceanographic labratory, Fisheries and Oceans (current meter and water property data),

- Canadian Hydrographic Service (water level and bathymetry data), and

- Atlantic Geoscience Centre, Geological Survey of Canada (bathymetry and bottom sediment data).

Also much of the available Grand Banks water property data of Canadian origin has been collected by or for Fisheries and Oceans in St. John's, Newfoundland.

Prior to about 1980 there was little relationship between government research and data collection activities and offshore hydrocarbon exploration programs. As a result the nature of data collected by government, and particularly the geographical distribution of these data, was not of immediate practical value to offshore operators. While the government necessarily continues to maintain its research-oriented programs quite apart from industrial activity in the offshore, there have been recent examples of cooperative industry/government programs yielding important data for drilling operators. Examples include:

- measurement and analysis programs conducted by C-CORE and the Atlantic Geoscience Centre, with industry support, in the investigation of iceberg scours on the Grand Banks; and

- analyses of industry collected current meter data on the Grand Banks by the Atlantic Oceanographic Laboratory.

6.1.3 Provincial Governments

Provincial government agencies in Canada's Atlantic provinces are not regarded as important sources of original oceanographic data relevant to exploration. However regulatory agencies such as the Newfoundland and Labrador Petroleum Directorate have a direct interest in the adequacy of baseline data for drilling program management. To date their activities have focussed on analysis of existing data rather than collection of new data.

6.1.4 Universities

The separation of university research activities in physical oceanography and offshore exploration parallels that described above for the Federal Government: until very recently the interaction of universities with offshore operators (with respect to physical oceanography) was minimal. With an increasing willingness of industry to both consult with and support university researchers, and with the evolution of three-way programs involving industry, university and federal government participation, the role of university as a source of oceanographic data is increasing. This role is not, however, expected to become major. Primary measurement programs, pertinent to offshore operations, will continue to be operated by industry and by large government agencies, with the university contribution being fairly small.

Examples of recent cooperative programs involving eastern Canadian Universities (principally Memorial University of Newfoundland and Dalhousie University) include:

- acoustic measurements of internal waves in Davis Strait conducted by Memorial University in conjunction with the 1980 Canterra Energy Ltd. drilling program;

- affiliation of industry, federal government and university representatives to form the Grand Banks Current Modelling Steering Committee; and

- field trials of experimental Coastal Ocean Dynamics Application Radar (CODAR) again involving industry, government and university resources and personnel.

6.1.5 International Agencies

Major contributions to the historical water property database, particularly on the Grand Banks but also offshore Labrador and off Nova Scotia, have been supplied by two international organizations -- the International Commission for the Northwest Atlantic Fishery (ICNAF) the International Ice Patrol (IIP) of the United States Coast Guard (USCG). Through ICNAF, ships from many nations which fish in Eastern Canadian waters (notably Portugal, Norway, USSR and Japan) collect and report hydrographic data. Similarly the IIP as part of their research efforts directed to computing geostrophic current patterns over the Grand Banks for the prediction of iceberg motion, have collected a substantial amount of hydrographic data. A further series of useful data, also collected and reported by the IIP, are trajectories of drogued buoys deployed over the Grand Banks. With the phasing out of shipboard ice surveillance in favour of aerial reconnaissance over the past 10 to 15 years, the role of the IIP as a collector of oceanographic data has diminished greatly.

6.2 Data Archives and Dissemination

6.2.1 Federal Archive Centres

The Canadian federal government has assigned to a series of agencies the responsibility for accumulation, quality-control, archiving and dissemination of physical oceanographic data. For some data types (e.g. water properties), such centres operate on a national basis while for others (e.g. current meter time-series data) regional archives are maintained. These agencies are intended to be the primary sources of data for dissemination to interested users.

The successful introduction of data to these archives has proven to be very dependent upon the source of the data. Industry data collected prior to about 1980 were under the constraint of a five year proprietary restriction and it was not until the 1980's that any substantial amount of such data was introduced to a formal archiving process. This is illustrated by the preparation and release of well site reports providing current meter records for Labrador locations occupied in the early to mid-1970's as recently as 1982 - 83. In the past five years, due principally to guidelines presented to industry by the Canadian Oil and Gas Lands Administration (COGLA), the flow of industry collected (well site) oceanographic data to archives has improved. Environmental measurements are now forwarded to COGLA within 60 days of well completion, and are then distributed by COGLA to the appropriate archive centres. The proprietary interval has been reduced from five to two years and in many instances, release of data even within the two year interval can be negotiated. Importantly, the data are at least being captured by the archive centres without long time delays and are being prepared for dissemination when their release is authorized.

This increased efficiency is expected to lead to improved data quality as problems are identified early enough that the personnel responsible for data collection can be contacted to resolve ambiguities or questions. This situation applies to data collected by industry in conjunction with actual drilling programs; other data collected by industry are much less likely to find quick entry into a government maintained archive. Specialized industry collected data are generally held for their full two year proprietary interval before being released for external distribution.

Federal government agencies collecting data suitable for entry into formal databases are expected to forward their data to the archive centres in a timely manner and in a fully documented format. Inspection of archived data (current meter time-series for example) from the 1960's and early to mid-1970's suggests that such orderly forwarding of data was not entirely successful. In recent years the accuracy and completeness of information submitted for archiving has improved, but archiving time delays of months to years are still encountered with government collected data.

Provincial government, university and international agencies are also requested by the archive centres to forward their holdings in timely fashion and with thorough documentation. The degree to which such acquisition is successful is questionable and may be particularly dependent upon the initiative of the originating scientist. Hence long time delays are common in the transmission of data from such groups and in its preparation for dissemination.

The three federal government archive centres relevant to this review are:

1) Marine Environmental Data Service (MEDS)

Address: 240 Sparks Street (7th Floor)
Ottawa, Ontario K1A 0E6

Contacts: Dr. J. R. Wilson, Director (613) 995-2007
Mr. J. J. Gagnon (613) 995-2014

Data Types: Water level, water property.

2) Atlantic Oceanographic Laboratory (AOL) Data Shop
Bedford Institute of Oceanography (BIO)

Address: P. O. Box 1006
Dartmouth, Nova Scotia B2Y 4A2

Contact: Mr. Doug Gregory (902) 426-8931

Data Type: Current meter time-series, Lagrangian drifter trajectories.

3) Canadian Climate Centre (CCC), Atmospheric Environment Service (AES)

Address: 4905 Dufferin Street
Downsview, Ontario M3H 5T4

Contact: V. R. Swail (416) 667-4995

Data Type: Sea surface temperature (stored in conjunction with synoptic weather observations from reporting vessels).

Acquisition of data from these archive centres is generally prompt compared to the delays associated with having data introduced into the archive. Low to moderate volume requests of a routine nature are typically fulfilled in two to four weeks while large volume or more complicated requests may require more than twice as long.

6.2.2 Source Agencies

In many instances there are requirements for physical oceanographic data prior to the time when these data are available for dissemination from formal archive centres or prior to their unrestricted public release. In such instances, it is frequently possible to negotiate early release of the data by direct contact with the sponsoring agency or company. Thus data source agencies are to be considered as an essential part of the dissemination network available for the distribution of data relevant to offshore operations.

6.2.3 International Agencies

Again due to delays inherent in accessing data through Canadian archive centres it is occasionally appropriate to request data directly from an international source agency. Such access is frequently time-consuming and costly and is not regarded as a primary option.

6.2.4 Proprietary Archives

Due to their substantial investment in data collection, and to their frequent and varied requirements for data utilization, certain companies operating in the east coast offshore have opted to establish and maintain their own proprietary archives of environmental data. These

systems have the advantage for the owner of potentially rapid updates, and of allowing retrieval of information in a matter of hours or days rather than weeks or months which government systems require. One example of this type of formal data archive is that maintained by Petro-Canada for its own use.

6.3 Data Distribution

A series of maps were shown in Figure 6.1 to give an impression of spatial data coverage in the intense hydrographic measurement campaigns carried out by industry. The stations in each area were all sampled over a few days, with several sampling sessions distributed over the year or open-water season. The following discussion presents similar information for data held in the Federal government archives. These latter data incorporate the industry measurements just referred to (Figure 6.1); however, near-shore data have been excluded from this summary since they are not relevant to exploratory drilling.

6.3.1 Moored Current Meter Data

The geographical distribution of moored current meter data off Canada's east coast is mapped in Figures 6.3 and 6.4. In the first figure all well sites at which current data have been collected are plotted. Table 6.1 gives the well site names and coordinates, year, number of instrument records obtained at the site, and the months spanned by the measurements. Figure 6.4 presents a tabulation of the number of current meter records archived by one degree squares, for instruments not deployed in association with a particular well site. Table 6.2 specifies the geographical region and the centre point coordinates of each one-degree square for

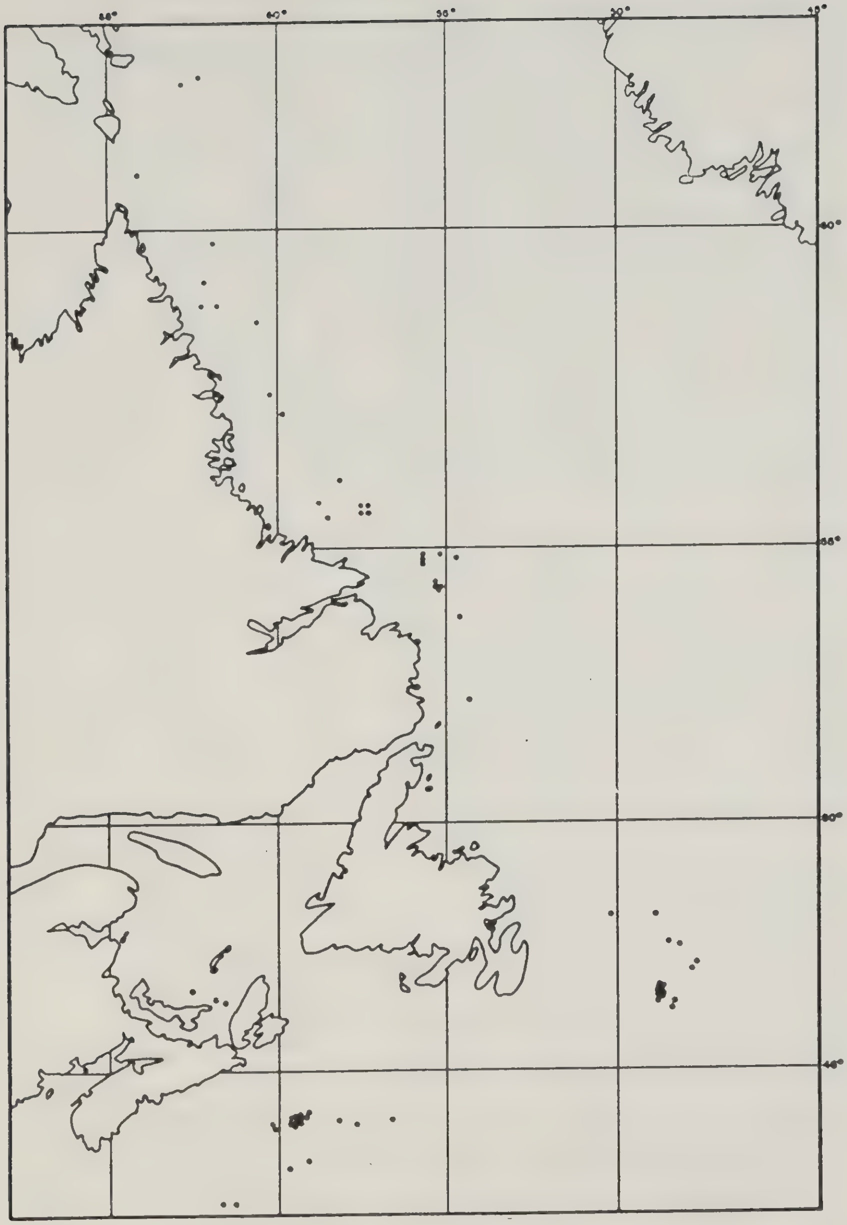


Figure 6.3 Locations of current meter data records associated with exploratory wellsites.

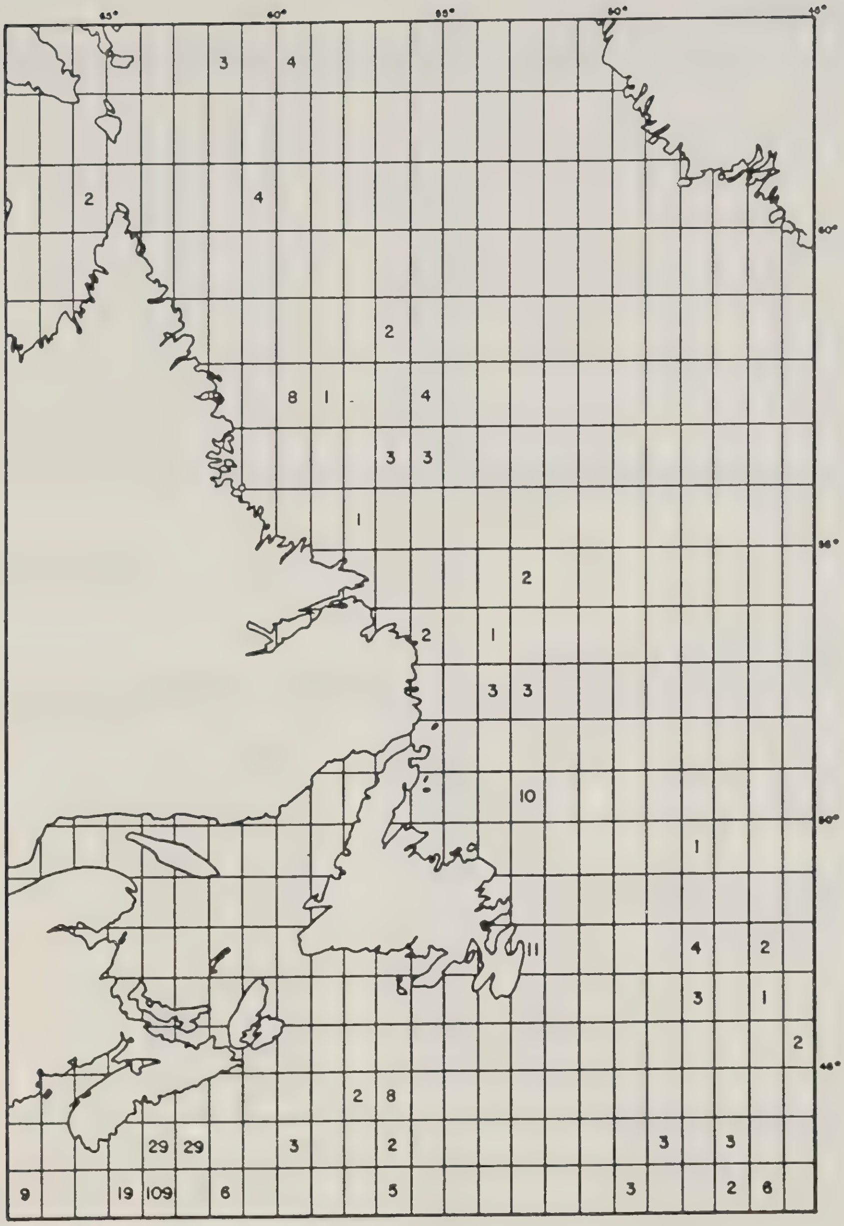


Figure 6.4 Location and number of moored current meter records collected independently of exploratory wellsites.

Table 6.1
Locations and Durations of Current Meter Data Records Associated with Exploratory Wellsites

General Region: Grand Banks

Wellsite	Location	Latitude - Longitude	Year	#Meters	J	F	M	A	M	J	J	A	S	O	N	D
					Deployment Period											
HIBERNIA O-35		46 44 - 48 49	1980	12	X	X	X	X	X	X	X					
BEN NEVIS I-45		46 34 - 48 21	1980	15				X	X	X	X	X	X			
HIBERNIA B-08		46 47 - 48 45	1980	9	X						X	X	X	X	X	X
SOUTH TEMPEST		47 07 - 47 57	1980	5	X									X	X	X
HIBERNIA G-55A		46 44 - 48 53	1980	3	X	X										X
HIBERNIA K-18		46 47 - 48 47	1981	10			X	X	X		X	X	X	X	X	
SHERIDAN J-87		48 26 - 49 57	1981	4							X	X	X	X	X	
NAUTILUS C-92		46 51 - 48 44	1981	12	X	X		X	X	X	X			X	X	X
WEST FLYING FOAM L-23		47 02 - 48 49	1981	2	X	X										X
HIBERNIA J-34		46 43 - 48 50	1981	3	X	X										X
BONANZA M-71		47 30 - 48 11	1982	9					X	X	X	X	X	X	X	X
LINNET E-63		48 12 - 50 25	1982	8							X	X	X	X	X	
NORTH DANA I-43		47 13 - 47 36	1982	11	X	X					X	X	X	X	X	X
HIBERNIA I-46		46 45 - 48 51	1983	6	X	X	X		X	X	X					
RANKIN M-36		46 35 - 48 50	1983	6					X	X	X					
HIBERNIA B-27		46 46 - 48 48	1983	5								X	X	X	X	X
HIBERNIA K-14		46 44 - 48 48	1983	6	X							X	X	X	X	X

General Region: Scotian Shelf/Gulf of St. Lawrence/Bay of Fundy

Wellsite	Location	Latitude - Longitude	Year	#Meters	J	F	M	A	M	J	J	A	S	O	N	D
					Deployment Period											
THEBAUD P-84		43 54 - 60 07	1972	1							X	X	X			
BLUENOSE G-47		44 06 - 59 21	1973	1		X	X	X								
INTREPID L-80		43 52 - 59 58	1974	3						X	X	X				
MIGRANT N-20		43 60 - 60 17	1977	4								X	X	X	X	
THEBAUD I-94		43 54 - 60 07	1978	1		X	X	X								
VENTURE D-23		44 01 - 59 34	1978	1									X			
VENTURE D-23		44 03 - 59 32	1978	1									X			
EAST POINT E-47		46 36 - 61 37	1980	None	(real time only)											
BEATON POINT F-70		46 39 - 61 54	1980	None	(real time only)											
BLUENOSE 2G-47		44 06 - 59 21	1983	9		X	X	X	X	X	X	X				
CABLEHEAD E-95		46 44 - 62 29	1983	None												
VENTURE B-13		44 02 - 59 32	1980	None												
VENTURE B-43		44 02 - 59 36	1981	5							X	X	X	X	X	
OLYMPIA A-12		44 01 - 59 46	1982	None												
SOUTH VENTURE O-59		43 58 - 59 38	1982	None												
VENTURE B-52		44 01 - 59 38	1983	None												
ARCADIA J-16		44 05 - 59 31	1983	None												
GLOOSCAP C-63		43 12 - 62 09	1983	9								X	X	X	X	X
CAPE SPENCER #1		44 45 - 65 40	1983	No information available												
UNIACKE G-72		44 11 - 59 41	1983	3					X	X	X	X				
S.W. BANQUEREAU F-34		44 03 - 59 50	1983	To be submitted												
GLENELG J-48		43 37 - 60 06	1983	6			X	X	X	X	X					
WEST ESPERANTO B-78		44 47 - 58 26	1982	To be submitted												
SHUBENACADIE H-100		42 49 - 61 28	1982	3	X											
NORTH BANQUEREAU I-13		44 12 - 58 31	1982	To be submitted												
BANQUEREAU C-21		44 10 - 58 34	1981	No measurements												

General Region: Davis Strait

Wellsite	Location	Latitude - Longitude	Year	#Meters	J	F	M	A	M	J	J	A	S	O	N	D
					Deployment Period											
RALEGH		62 16 - 62 24	1979	3								X	X			
RALEGH N-18		62 18 - 62 33	1982	11							X	X	X	X		
FINNBOGI		60 50 - 64 01	1979	5								X	X			
HEKJA O-71		62 11 - 62 59	1980	8								X	X	X		

Table 6.1 (continued)

General Region: Labrador Shelf

Wellsite	Location	Latitude - Longitude	Year	#Meters	J	F	M	A	M	J	J	A	S	O	N	D
LEIF E-38		54 17 - 55 05	1973	2							X	X				
LEIF E-48		54 17 - 55 07	1973	2								X				
BJARNI H-81		55 30 - 57 42	1973	3								X	X	X	X	
GUDRID H-55		54 54 - 55 52	1974	2							X	X	X	X		
BJARNI H-81		55 30 - 57 42	1974	2										X		
FREYDIS B-87		53 56 - 54 42	1975	2							X	X				
SNORRI J-90		57 19 - 59 57	1975	1							X	X	X	X		
KARLSEFNI A-13		58 52 - 61 46	1975	2								X	X			
CARTIER D-70		54 59 - 55 40	1975	2									X	X		
CABOT G-91		59 50 - 61 43	1976	2							X	X				
INDIAN HARBOUR M-52		54 21 - 54 23	1976	1								X	X	X	X	
HERJOLF M-92		55 31 - 57 44	1976	2								X	X	X	X	
SNORRI J-90		57 19 - 59 57	1976	1								X	X			
VERRAZANO L-77		52 26 - 54 11	1976	2									X			
KARLSEFNI A-13		58 52 - 61 46	1976	2									X	X		
ROBERVAL K-92		54 51 - 55 44	1979	1							X	X	X	X		
TYRK P-100		55 29 - 58 13	1979	1							X	X				
BJARNI O-82		55 31 - 57 42	1979	1							X	X	X	X		
GILBERT F-53		58 52 - 62 08	1979	1								X	X	X		
ROBERVAL C-02		54 51 - 55 46	1980	2							X	X	X			
GILBERT F-53		58 52 - 62 08	1980	2							X	X	X			
OGMUND E-72		57 31 - 60 26	1980	2								X	X	X		
NORTH LEIF I-05		54 24 - 55 15	1980	2									X			
SOUTH LABRADOR N-79		55 48 - 58 26	1980	3								X	X	X		
BJARNI O-82		55 31 - 57 42	1980	1									X	X		
NORTH BJARNI F-06		55 35 - 57 45	1980	2									X	X		
ROBERVAL K-92		54 51 - 55 44	1980	2									X			
BJARNI O-82		55 31 - 57 42	1981	2							X	X	X			
NORTH LEIF I-05		54 24 - 55 15	1981	2						X	X	X	X	X		
RUT H-11		59 10 - 62 16	1981	2							X	X	X	X		
NORTH BJARNI F-06		55 35 - 57 45	1981	1						X	X	X	X	X		
ROBERVAL C-02		54 51 - 55 46	1981	2							X	X	X	X		
CORTE REAL P-85		56 04 - 58 12	1981	None												
POTHURST P-19		58 48 - 60 31	1982	3							X	X	X	X		
CORTE REAL P-85		56 04 - 58 12	1982	2								X	X	X		
RUT H-11		59 10 - 62 16	1982	3								X	X	X		
ROBERVAL K-92		54 51 - 55 44	1982	None												
RUT H-11		59 10 - 58 12	1983	3								X	X	X		
CORTE REAL P-85		56 04 - 58 12	1983	1							X	X	X	X		
SOUTH HOPEDALE L-39		55 48 - 58 50	1983	3							X	X				
POTHURST P-19		58 48 - 60 31	1983	To be submitted												
PINING E-16		54 54 - 55 03	1983	To be submitted												
SOUTHERN CROSS-2		52 17 - 52 50	1981	3						X	X	X	X	X		
SOUTHERN CROSS-6		52 20 - 52 42	1981	3						X	X	X	X	X		
SOUTHERN CROSS-7		52 32 - 52 08	1981	3						X	X	X	X	X		

The month columns J–D are headed "Deployment Period".

Table 6.2

Locations and Durations of Current Meter Data Records Collected Independently of Exploratory Wellsites

General Region/ Geographical Location	Reference Coordinates (Latitude, Longitude)	Year	Total # Instruments	Deployment Interval J	F	M	A	M	J	J	A	S	O	N	D
Ritu Bank	50 30 - 52 30	71	10						X						
Flemish Pass	46 30 - 47 30	76	3				X	X	X	X					
	47 30 - 47 30	76	4							X	X	X	X		
Labrador Sea	56 30 - 55 30	76	3			X	X								
	56 30 - 56 30	76	3			X	X								
Labrador Slope	57 30 - 59 30	77	5	X									X	X	X
Davis Strait	60 30 - 60 30	77	4								X	X	X		
	60 30 - 65 30	77	2									X	X		
	62 30 - 59 30	77	4								X	X	X		
	62 30 - 61 30	77	3								X	X	X		
Labrador Shelf	53 30 - 55 30	78	1	X	X	X	X	X	X	X	X		X	X	X
Labrador Sea	57 30 - 55 30	78	4			X									
Labrador Slope	57 30 - 58 30	78	1	X	X	X	X	X	X	X					
	57 30 - 59 30	78	3	X	X	X	X	X	X	X					
	58 30 - 56 30	78	2	X	X	X	X	X	X	X					
Flemish Cap	46 30 - 45 30	79	1	X	X	X	X	X	X	X					
	47 30 - 45 30	79	2	X	X	X	X	X	X	X					
Labrador Sea	49 30 - 47 30	79	1							X					
	55 30 - 57 30	79	1								X				
Avalon Channel	47 30 - 52 30	80	11	X	X	X	X		X	X	X	X	X	X	X
Labrador Shelf	53 30 - 53 30	80	1							X	X	X	X		
	53 30 - 55 30	80	1							X	X	X	X	X	
	54 30 - 52 30	80	2							X	X	X	X		
Belle Isle Bank	52 30 - 52 30	81	3						X	X	X	X	X		
	52 30 - 53 30	81	3						X	X	X	X	X		
Tail of the Grand Banks	42 30 - 45 30	72	6				X	X	X						
	42 30 - 46 30	72	2				X	X	X						
	42 30 - 49 30	72	3				X	X							
	42 30 - 48 30	72	3				X	X							
Tail of the Grand Banks	45 30 - 44 30	81	2				X	X							
Scotian Shelf	42 30 - 63 30	67	7					X	X	X	X				
	43 30 - 62 30	67	18												
	43 30 - 63 30	67	4	X	X	X		X	X	X	X	X	X	X	
Scotian Shelf	42 30 - 61 30	68	2									X	X		
	42 30 - 63 30	68	7									X	X	X	
	43 30 - 59 30	68	3									X	X		
	43 30 - 62 30	68	9	X									X	X	X
	43 30 - 63 30	68	8						X	X	X	X	X		
Scotian Shelf	42 30 - 61 30	73	4			X	X								
Laurentian Fan	42 30 - 56 30	74	5						X						
Scotian Shelf	42 30 - 63 30	75	3	X	X	X	X								
Laurentian Fan	43 30 - 56 30	75	2		X	X	X								
	44 30 - 56 30	75	8				X	X	X	X	X	X	X	X	X
Banquereau Bank	44 30 - 57 30	75	2						X						
Scotian Shelf	42 30 - 63 30	76	50	X	X	X	X	X	X	X	X	X	X	X	X
	42 30 - 64 30	76	14	X	X	X			X	X	X	X	X	X	X
	43 30 - 63 30	76	9	X	X	X				X	X	X	X	X	X
Scotian Shelf	42 30 - 63 30	77	28	X			X	X	X	X	X	X	X	X	X
	42 30 - 64 30	77	5	X			X	X	X	X	X	X	X	X	X
	43 30 - 63 30	77	8	X			X	X	X	X	X	X	X	X	X
Georges Bank	42 30 - 67 30	78	9										X	X	
Emerald Basin	43 30 - 62 30	79	2											X	
Scotian Shelf	42 30 - 63 30	80	7											X	
Scotian Shelf	42 30 - 63 30	81	7											X	

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which measurements are available. For each year, the total number of instrument records, and the composite time span (months) for these records are also given. No attempt is made to show how much of the data is valid within these time spans, and this will vary for different instruments. Generally the analyst must deal with record gappiness in any subsequent processing using, for example, the models described in the last chapter.

The data are generally stored in time series format although the amount of preprocessing may vary depending upon the source. As a rule, current and water property data measured simultaneously, will be archived in calibrated, despiked form at the sampling interval of the instrument. Occassionally, however, data may be averaged and/or subsampled to hourly values. Differences in despiking procedures, averaging or smoothing, and subsampling methods mean that archived data are not of uniform quality and meaning. Because these data may also be accessed without reference to documentation on instrument performance they require a knowledgable and critical user.

6.3.2 Lagrangian Surface Current Data

While none of the archives listed above maintains a a comprehensive file of all Lagrangian surface current data, there do exist three data sets which are potentially valuable. A data set of release/recovery statistics for drift cards deployed off Nova Scotia and Newfoundland and in the Gulf of St. Lawrence prior to about 1980 resides at MEDS and is available for external distribution. A more recent set of drift card data for these same regions is beign maintained at C-CORE, but it is not widely

Figure 6.5 Locations of permanent water level recording stations maintained by the Canadian Hydrographic Service.

distributed. Finally, a composite set of drifting buoy trajectories for the Grand Banks is held at the Bedford Institute of Oceanography and is shortly to be reported by Petrie and Isenor (1983). As is the case with the recent drifter data, these buoy data have not received broad distribution except as lists of buoy coordinates published in annual reports of the International Ice Patrol.

A small number of drifting buoy trajectories exist for the Hudson Strait, Labrador Shelf region as well. These data were collected by Esso Resources Canada Limited and Canterra Energy Ltd. and are available from these companies.

6.3.3 Water Level Stations

Figure 6.5 shows the locations of permanent water level recording stations in the study area. Long-term measurements are available at this site, together with tidal harmonic constituents, from the Canadian Hydrographic Service (CHS). Since 1981, water level data have also been obtained at Sable Island (CHS) and at several offshore sites on the Grand Banks, Labrador, Davis Strait and the southern Scotian Shelf. These are relatively short-term datasets collected for tidal analysis.

6.3.4 Water Property Stations

The historical collection of water property data, maintained in Ottawa by MEDS for the east coast offshore, is large incorporating in excess of 170,00 stations, and spanning the years from about 1920 to the present. Figure 6.6 illustrates station counts in ten-degree areas. The stations included here may have bottle samples, mechanical bathythermograph profiles and/or conductivity/temperature/depth profiles recorded using STD or CTD profilers.

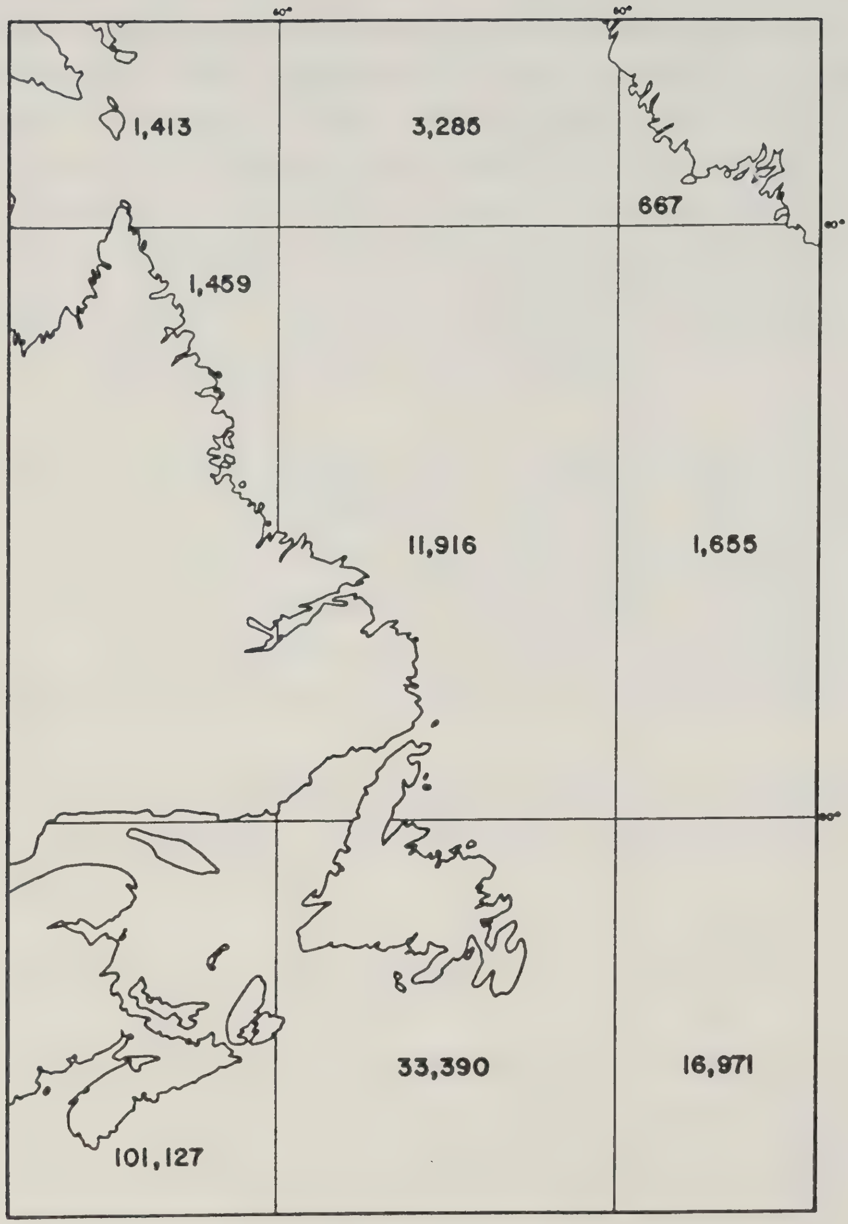

Figure 6.6 Number of water property sampling stations by ten-degree area.

Seasonal coverage is not particularly good in the more northern regions and even on the Grand Banks and Scotian Shelf a disproportionately high percentage of the observations are confined to summer months. A sequence of monthly charts of mean sea surface salinity is shown in Figure 6.7 to demonstrate how the increased data coverage in summer months leads to both better resolution of features using an objective contouring routine, and extended coverage into the Labrador Sea and the outer regions of the Grand Banks and Scotian Shelf.

Lack of winter-spring data in the Labrador Sea and Davis Strait is understandable in light of operating difficulties in ice-infested waters, but has the obvious consequence that very little is known about winter conditions in those areas. To date this has no bearing on exploratory drilling there which is confined to this ice free season.

The database for each station includes temperature and/or salinity and/or dissolved oxygen concentration data as a function of depth.

6.3.5 Evidence of Internal Waves

Current and water property data specifically linked to internal waves are not archived at any of the centres listed in Section 6.2. However, data on internal solitons, collected by Aquitaine Company of Canada Ltd. during drilling of the HEKJA 0-71 well in Davis Strait (Hodgins and Westergard, 1981; Hodgins and Hodgins, 1981; Cummins and LeBlond, 1984), are accessible through Canterra Energy Limited in Calgary. Other data on large internal waves over the Scotian Shelf have also been collected and analyzed by Sandstrom and Elliott (1983).

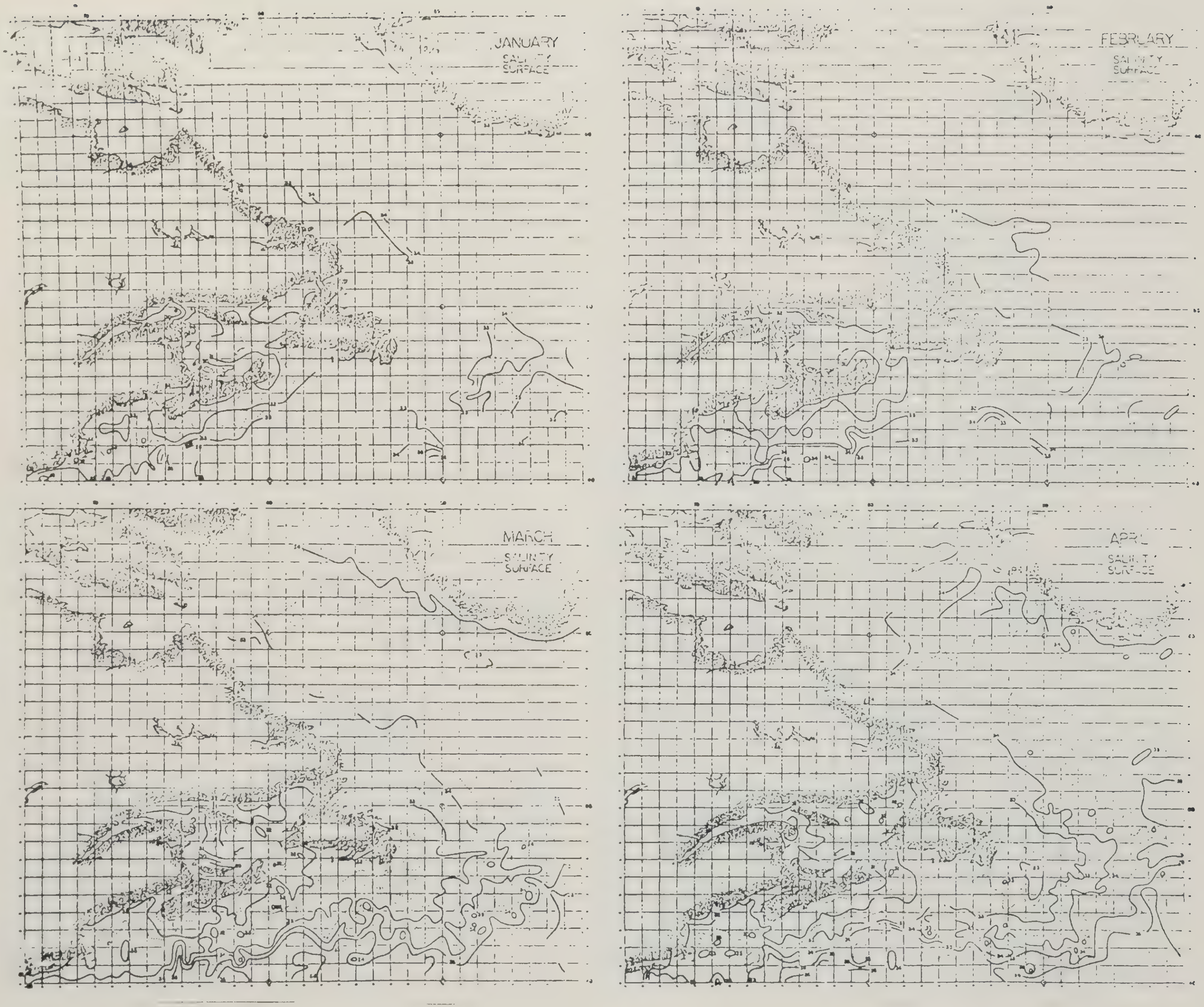

Figure 6.7 Monthly mean sea surface salinity charts for the Canadian East Coast. These illustrate the increased resolution and areal coverage during summer months (source: MEDS).

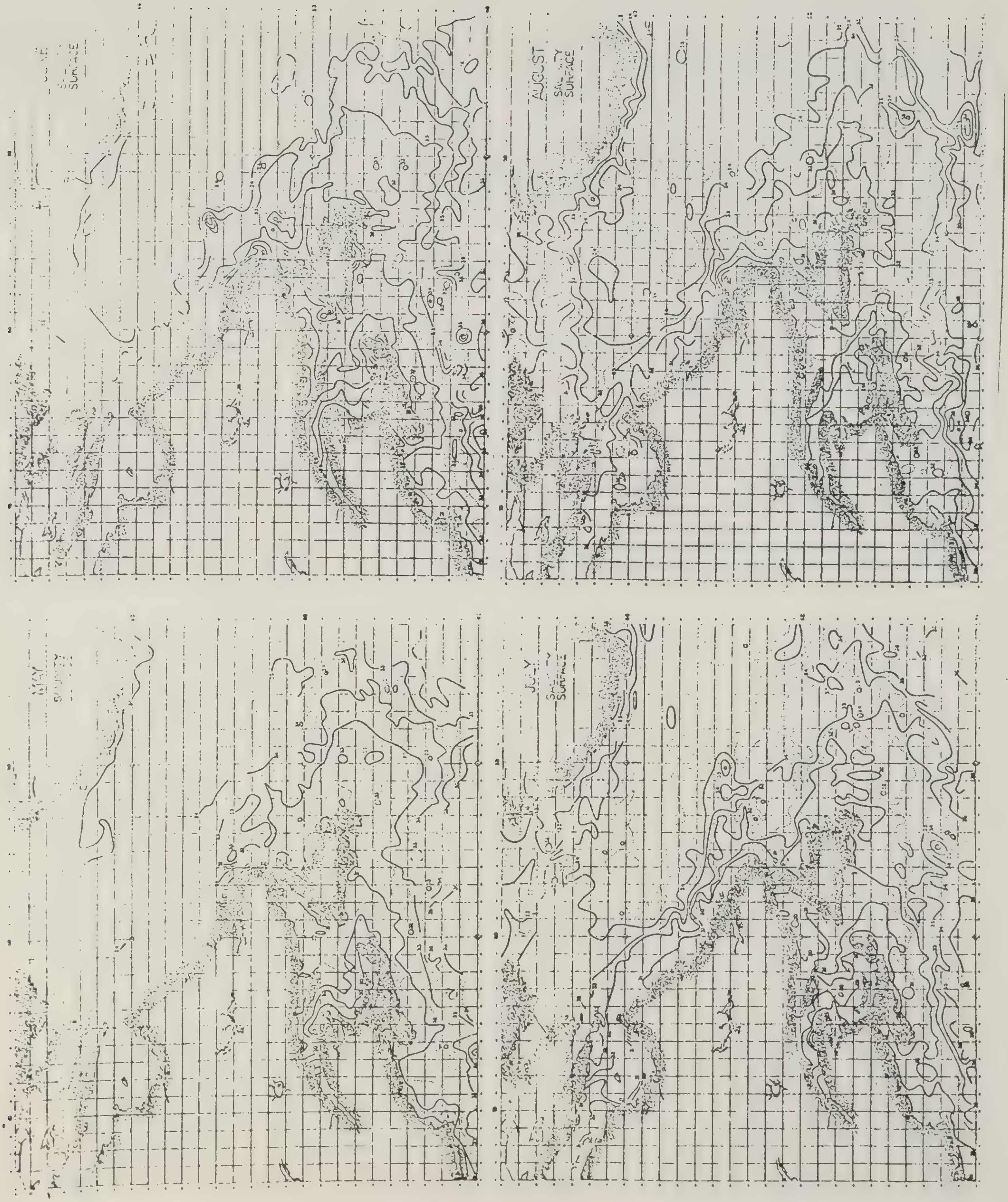

Figure 6.7 (continued)

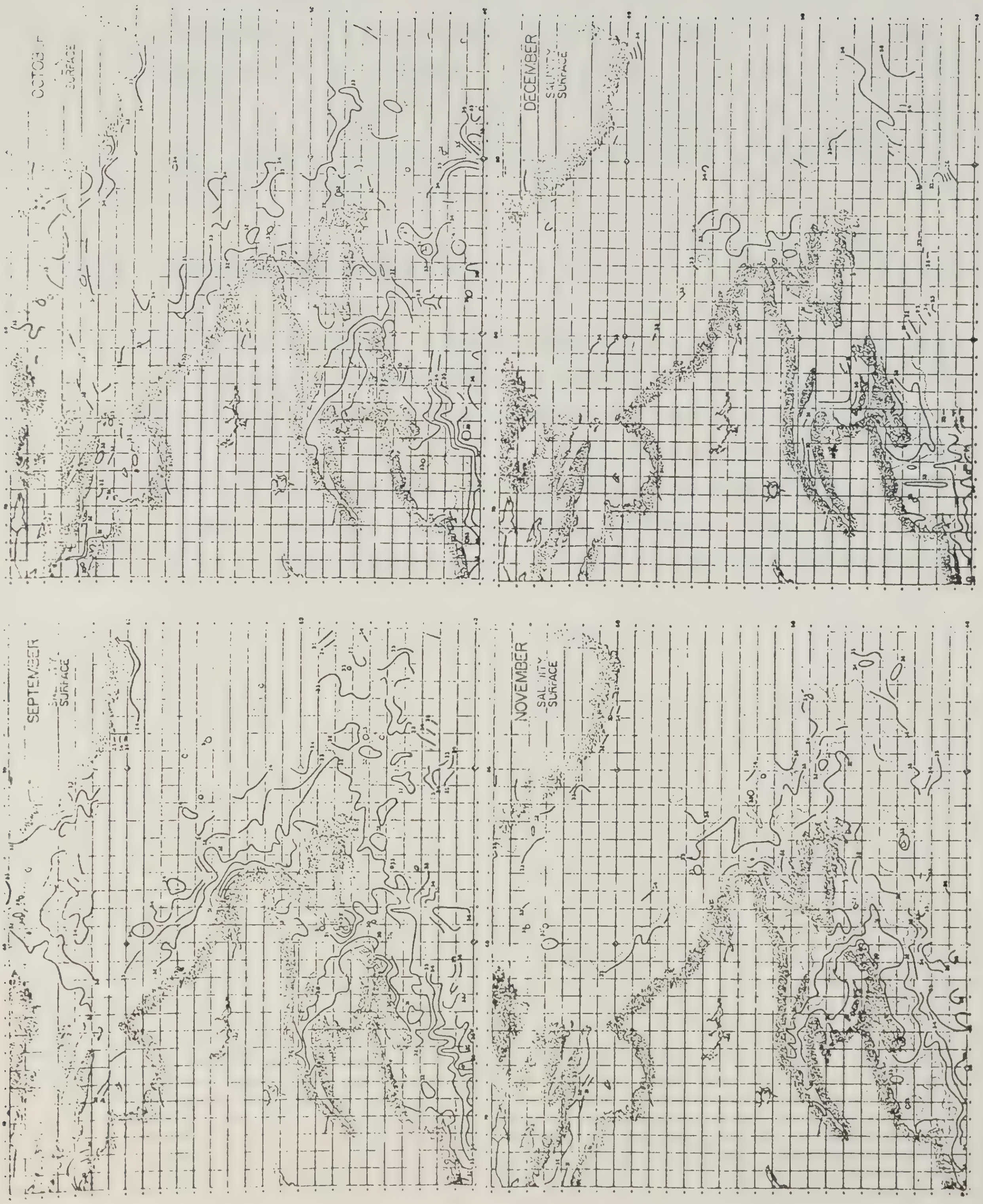

Figure 6.7 (continued)

These data may be available from the Bedford Institute of Oceanography. Satellite imagery of internal wave signatures is also available from the Jet Propulsion Laboratory in Pasadena, California and from the Canada Centre for Remote Sensing. Fu and Holt (1982) describe the SEASAT synthetic-aperture radar image of internal waves in Davis Strait.

6.3.6 Evidence of Biofouling

The only explicit investigation of biofouling pertinent to offshore hydrocarbon exploration on the Canadian east coast is found in a proprietary study undertaken for Mobil Oil Canada, Ltd. in 1982 as a preliminary assessment of the phenomenon. Any additional information at present must be inferred from documentation of fouling rates and accumulations on such structures as wharves and buoys.

7. GENERAL CONCLUSIONS

The preceeding discussion has defined the oceanographic parameters that are pertinent for exploratory drilling, omitting surface wind waves which are discussed in a separate report by Wilson and Baird (1984), and has outlined measurement techniques widely used now to quantify these parameters. Analysis methods, by which oceanographers seek causative explanations for observed features, were then discussed, followed by an overview of predictive models that attempt to extrapolate observations in time or to spatially interpolate them. Finally, in the preceeding chapter, a broad-brush picture of the distribution of available data was presented. This organization has laid the groundwork upon which to base a number of conclusions dealing with:

1) the appropriateness and adequacy of how physical processes in the ocean are described, parameterized, and measured;

2) the effectiveness of analytical (and theoretical) methods for understanding these processes;

3) the adequacy and potential of predictive models from a theoretical standpoint, and in view of existing data; and

4) the nature of and shortcomings found in presently available data, and what these mean to offshore operations.

Before presenting our final conclusions it will be useful to reconsider the problem at hand: i.e. making quantitative descriptions of oceanographic properties in a manner to meet the diverse needs of offshore operators.

The perspective is on the design and safe operation of drill rigs and drilling programs. Oceanographic data as they may be used for oil spill countermeasures on environmental impact assessments are not considered here.

7.1 Oceanic Processes

In looking at the ocean attention is focussed on its motion; either as it exerts a load on the drilling unit or as it affects downhole or diving operations. The dominant characteristic of this motion is its variability, and the multiplicity of space and time scales over which it occurs. At the largest scales and longest periods (several tens of kilometers and days to months) the important influences are seasonal changes in weather and runoff and variations in topography. At slightly smaller scales, cyclical storm winds, continental shelf waves, meanders and baroclinic instabilities all contribute to displacing and changing the large-scale currents that affect a given site. At scales of a few tens of kilometers and periods of a few hours to about one day, tides and storm-generated currents are present. Both bathymetry and local stratification play major roles in modifying these flows. At the smallest scales, of a few hundred metres and a few minutes in time, internal waves account for most of the fluctuating motion. In places these waves may have very large amplitudes and generate strong currents.

Instruments, analytical techniques and some predictive models are geared at resolving and explaining some but not all of these scales. This affects two aspects of the problem. First, estimating extreme currents relies generally on being able to predict how variations, ideally over all scales, combine to give the worst flow condition at a known probability of occurrence and with

some acceptable confidence. Second, environmental conditions which may threaten human safety during normal operations (e.g. diving; handling BOP's, risers, casing and drill stem; resupply) are often associated with rapid and localized phenomena. It is precisely those phenomena that are poorly measured and among the least predictable at present.

7.2 Conclusions

7.2.1 On Parameterization and Measurement

In describing ocean currents and water masses, basic physical parameters -- speed and direction at a point, temperature, salinity and density -- are, and have always been used in modern oceanography. These are entirely appropriate because they are fundamental to a dynamical understanding of currents, and are with the exception of density directly measured in the ocean. Sensors have been developed to measure these parameters accurately, and the instruments and mooring techniques now used in offshore waters are adequate for most purposes.

The Aanderaa RCM4 current meter is still the most widely deployed instrument for monitoring flows despite its not being a proper vector-averaging meter. This is a weakness in offshore measurements. Improved reliability would follow from a general replacement of Aanderaa meters with vector-averaging instruments. In view of the present high cost of these newer meters there appears to be a real need for a less expensive device.

Regulatory guidelines have dictated use of three current meters distributed over the water column at 20 m depth, mid-depth and near-bottom, usually 20 m above the sea bed.

Much available data has come from these moorings placed by the offshore operators. In shallow areas, less than about 100 m depth, 3 meters may give adequate vertical resolution of currents. In other areas, e.g. along the Labrador shelf, this scheme may not be satisfactory: the spacing between the meters may well bracket core currents. Frequently, the description provided of wind-driven currents and internal wave motions at tidal frequencies linked to the pycnocline, will be unsatisfactory to verify predictive or interpretive models. Instrument deployments rationalized for dynamical oceanographic needs and taking existing knowledge into account would lead to more useful data.

Instruments for detailed sampling of temperature and conductivity over depth are fully developed. They provide data on vertical density stratification essential to the prediction of wind-driven current extremes. Regulatory guidelines do not make collection of these data necessary in conjunction with current meter deployments by industry. This is a serious shortcoming in these measurement programs since the absence of the data greatly limits interpretation and modelling.

7.2.2 On Analytical Techniques

The purpose of data analysis methods is to produce valid observations from instrumental records, and to separate motions into components that can be explained by various forcing mechanisms. Included in this latter aspect would be techniques to reveal those characteristics of the flow resulting from the interaction of waves (e.g. tides) with the bathymetry. This is an area, tied to predictive models, of extremely active research in the

oceanographic community. New procedures may be expected to come along regularly.

There is no evidence to suggest, however, that analytical methods are inadequate for data being collected in Canadian waters. Problems that exist have more to do with what data are collected, and where, than with the processing methods used on them.

7.2.3 On Predictive Techniques

Statistical methods for deriving extreme currents rely on having a long time-series of data. Ideally these are directly measured current data at a sufficient number of depths over the water column to define a velocity profile. Alternatively the current data could be hindcasted using empirical or deterministic models but there are limitations imposed by the quality of the wind data and by the models themselves. Rules for how long the time-series should be are lacking; Osborn et al. (1978) looked at this problem in Davis Strait. They found, using the results of Flierl and McWilliams (1977), that errors in mean flow estimates would be about ±50% (±10 cm/s in 20 cm/s) for the 60-day records there. To improve significantly on this estimate, about 3 years of continuous sampling would be required. They noted further that to achieve a ±10% error in the variance of the mean flow (important for estimating extremes) about 28 years of data would be needed. Also, by analogy with extreme wave estimation, one would require many years of data which is consistent with the above estimates.

These conditions are not fulfilled anywhere in Eastern Canadian offshore waters. In only one area near Hibernia,

are there several years of data (about 3). Even here, though, the data were collected at slightly different locations and while one expects the current differences to be small, differences must necessarily exist and have some influence on the accuracy of the predicted extremes. Moreover, the quality of instrumental measurements improved with time so that the database has uneven accuracy.

Tidal Currents

In general where there are 30 or more days of measured currents (hourly or more frequent sampling) tidal currents can be predicted by the harmonic method (e.g. Foreman, 1978). Since most instrument deployments are longer than 30 days, estimates of maximum tidal currents that are likely to be adequate for rig evaluation and drilling operations can be made at the measurement locations. The accuracy of these predictions has yet to be established, however, and this limits confidence in the extremes.

A more serious problem arises when attempting to interpolate tidal currents between measurement sites. The bathymetry of the continental shelves, and the coastal landforms, produce strong spatial variations in tidal flows (e.g. the area surrounding the mouth of Hudson Strait where tidal flows exceed 5 knots). These effects can, in principle, be calculated using numerical hydrodynamic models given tidal water level variations along the model boundaries. However, water level data at strategic deep sea points are lacking over most of the study area. Exceptions include the extreme southern Scotian shelf (see e.g. Greenberg, 1983) and a program underway as of April 1984 to collect data around the Grand Banks.

Thus, it appears that predictions of the magnitude and timing of maximum tidal currents at specific data locations can be made with reasonable accuracy. Because data points are clustered, and spatial variations in tidal flows can be strong, interpolating site-specific data will be difficult. Deterministic models offer the potential to do this with reasonable accuracy; to date, however, this type of modelling has not been carried out and is constrained by lack of deep-sea water level data.

Wind-Driven Currents

Wind generated current extremes can be estimated using statistical models, or deterministic models forced by 50 or 100-year return wind histories. The first method requires that wind-driven currents by isolated from measurements, which is possible with present analytical techniques, and that the records span many years. This latter condition is not met by records in the study area.

Deterministic modelling driven by a time-series of local wind stress at the sea surface has the potential to provide good current predictions if the density stratification giving rise to the maximum response can be specified. In principle this is possible from the water property data archived by MEDS in Ottawa, although there may be some uncertainty introduced by the interpolation over depth. The second requirement is for field data to calibrate the models. These data are available over the Hibernia area, and the Scotian Shelf around Sable Island, where they have been measured with proper vector-averaging current meters. Elsewhere calibration data are few.

Earlier we have described empirical models based on the multiple coherence between wind and measured currents. This has the potential to greatly extend the measured database by hindcasting currents from long-term wind records. These methods have not been applied to any location within the study area, but could be with a reasonable chance of success for Hibernia and some sites near Sable Island.

Residual Currents

Low-frequency background currents produced by density variations and seasonal changes in the surface wind stress distribution can only be predicted with confidence using statistical models based on time-series measurements; again, the requirement is for multi-year data sets, which are not available. Spatial variations are also large, depending on bathymetry and topography; thus interpolating between measurement sites is extremely difficult. Regional maps of geostrophic currents do exist for may areas of exploratory interest but these provide only the roughest guide to where major currents may be located and their average flow speeds. These maps are of extremely limited accuracy in the engineering sense because they account for only a fraction of the net flow (e.g. ≈ 50% in the Baffin Current; Osborn et al., 1978) and reveal nothing about the variability of the flow over time scales of a few days to weeks.

Residual currents can not be neglected in the derivation of extremes. Much of Canada's eastern acreage is located in or near the major ocean currents along the coastline. These include the Baffin Current in Lancaster Sound, Baffin Bay and Davis Strait (max. speeds ranging from 50 to 80 cm/s) and the Labrador Current along the Labrador Coast and the eastern edge of the Grand Banks (max. speeds

ranging from 35 to 70 cm/s). In these areas the residual currents may exceed the tidal currents away from the coastal zone. Measurements will be required to estimate extremes of speed in these areas.

Three-dimensional deterministic modelling incorporating density variations and changes in atmospheric forcing could, in principle, be applied; however, sufficient data to initialize and run these models are not available. The cost of computing for models of this kind, together with uncertainties in the results due to assumptions made in their formulation, make them impractical as well. Instrumental measurements, even for a short period, are to be considered more reliable than model predictions at this time.

High-Frequency Currents

Rapidly fluctuating currents, with periods of a few minutes to a few hours, are often disregarded when estimating extreme design currents. They are caused by such factors as internal waves near the surface, or by gravity currents along the sea bed, and can be sufficiently strong to disrupt drilling operations. Diving is particularly sensitive to rapid changes in current. Because large high-frequency currents are either rare or sporadic, their prediction is nearly impossible.

This situation results from a poor understanding of their causes, e.g. what triggers the formation of solitons in Davis Strait (Hodgins and Westergard 1981), and how they propagate through the ocean. There are weakness with theoretical models and a severe lack of oceanic observations.

Historical data have all been collected (with the exception of the Davis Strait soliton work) with a view to ignoring high-frequency signals. Instruments were used with too long sampling intervals to resolve internal waves or were placed too high above the sea bottom to record large currents there.

It appears, however, that potentially dangerous current events are rather rare in the Eastern Canadian offshore. Prediction will rely on measuring the phenomena that affect a given site, determining their frequency, and periodicity if any, and using this information to anticipate the event to schedule accordingly.

New data will be required to discover these phenomena (satellite imagery as well as conventional in situ measurements) and real-time data may well be needed to carry out exploratory operations. These techniques were successfully applied in Davis Strait for detecting solitons. We note that large amplitude internal waves have also been observed on the edge of the Scotian Shelf and tidal conditions along the Grand Banks may generate waves there. To date, though, no observations have been made of large internal waves over the Grand Banks.

7.2.4 On Available Data

Current Meter Data

Current data have originated from three basic sources: government scientific research, industry baseline studies of a regional nature, and industry deployments in conjunction with well drilling. The last contribution is the largest. Considered together, and looking at the spatial distribution of data and the record durations at each location, no multiyear master plan has

evolved that is oceanographically sensible. Rather what is available now is a haphazard set of short-term records largely clustered around areas of active drilling or discovery. Systematic long-term measurements at strategic locations, locations that would delineate major currents and that would provide input data for predictive modelling, have not been undertaken.

Regulatory guidelines for the industry have led to a policy of deploying current meters proximate to well sites regardless of the time taken to complete a drilling program. There has been no impetus or necessity for measurements at fixed locations that would be of an essentially continuous nature. The guidelines produced data that were useful, perhaps, for answering questions about changes in proposed drilling programs on a well-by-well basis, but of much lower applicability for deriving long-term extremes. Such an approach was understandable in the early years of exploratory drilling but is less obviously correct in the light of discoveries and greatly expanded drilling in certain areas (e.g. the North East Grand Banks).

Thus it is possible to use some data for the derviation of extremes, but due to changes in instrument types and mooring locations, it involves a great deal of judgement and patching together of records. Assumptions must be made about spatial variability with little hard evidence for guidance.

Combined Data

Any meaningful interpretation or modelling of ocean currents requires concurrent data on density variations over depth, and local and far-field winds. Local anemometer winds are generally available with industry data,

but are seldom measured in government programs, even in terms of installing automatic shorebased weather stations. In none of the database archives are meteorological data incorporated into the current meter records, although the data do exist and can be obtained by going to separate agencies such as the Atmospheric Environment Service.

Conductivity and temperature depth profile data are not routinely collected with industry current monitoring and this is a serious shortcoming. As a result, detailed stratification data at the time and location of current measurements are generally lacking. This greatly constrains the interpretation of current observations, especially with respect to estimating wind-driven extremes. As with wind, stratification data that do exist are not identified and archived with current meter records.

This means that dynamical studies of maximum currents must assemble data from several different sources, a time-consuming and often unsatisfactory task because of differences in the way data are identified and stored and in their quality. As noted above it seems as if no master plan or strategy oriented toward understanding currents, and the prediction of extremes of speed in response to natural forcing mechanisms, has been adopted for data collection and archiving. This arguement can be extended also to wave data. As noted by Wilson and Baird (1984) the attention of offshore designers and operators is turning more and more to the joint occurrences of extremes of wind, waves and currents. The separation in Canadian practice of how these data are measured, processed and archived for climatological analysis makes this type of study difficult at present.

Concluding Remarks

From an oceanographic perspective there are many shortcomings in how data are collected and stored for later use, and these have a direct impact in how well design currents can be evaluated. Available data are not adequate to derive current extremes with the confidence that one normally associates with wind or wave criteria. However, the existing data, scientific interpretation of them and industry studies have not revealed conditions that are beyond the drilling technology in use today, nor that appear to be limiting for design over most of the East Coast. A decade of offshore experience has also failed to turn up serious problems that could be attributed to ocean currents or extremes of temperature. The effects of waves and ice are much more serious.

One area of obvious concern is the mouth of Hudson Strait because currents there are very strong. Operational problems would be expected with spudding, BOP handling, riser design and drill rig station keeping. There are some data for the region collected in 1979, and industry are aware of the conditions to be faced. Safe drilling is a matter of sound engineering, and this would demand more data than are available now.

Also as exploratory drilling moves into deeper water along the edges of the continental shelf the role of currents may be expected to increase. One area of interest is Flemish Pass where because of the bathymetry the outer branch of the Labrador Current is focused into a strong, persistent flow. Clearly the potential exists for large currents, with a complex vertical structure, resulting from storm currents combining with the more permanent Labrador Current. Here also more data, over many depths, are required.

The evaluation of rig performance and seakeeping ability demands that the vessel be analyzed for worst-case combined loads, due to winds, waves, and currents. Traditional practice has involved adding up the individual extremes as derived largely from distinct and separate analyses of the various data types. Canadian practice has, seemingly, oriented data collection and archiving to respond to this approach. A major hurdle to examining combined events in nature is the separation of historical data in different archives, some missing data, and uneveness in quality. More detailed, data-based studies into the response of the atmosphere and ocean together under extreme forcing is desirable; it would lead to more rational and realistic conditions for rig evaluation in any of the operating modes (transit, survival or drilling).

If we look ahead and anticipate more offshore drilling, followed by production, it would seem logical to reorient oceanographic data collection along more rational lines than are presently followed. Essential aspects include:

1) establishing predictive techniques for current extremes, and determining data requirements for them;

2) organizing long-term strategic monitoring stations that would provide meteorological, wave, current, and water property profile measurements;

3) standardizing instrumental and analytical techniques; and

4) putting all data into one archive suitable for a dynamical analysis of winds and currents, in combination with wind waves.

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